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TECHNICAL REPORT ECOM-02173-4

METEOROLOGICAL SATELLITE TECHNIQUES FOR THE ARMY

FINAL REPORT

BY
PAUL E. SHERR, JAMES C. BARNES, ROLAND J. BOUCHER,
C. WILLIAM ROGERS and WILLIAM K. WIDGER JR.

JUNE 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N. J.
CONTRACT NO. DA28-043-[illegible] 01273(E)
ARACON GEOPHYSICS COMPANY
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CONCORD, MASSACHUSETTS

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ERRATA FOR

METEOROLOGICAL SATELLITE TECHNIQUES

FOR THE ARMY

ECOM-01273-4

Contract No. DA 28-043-AMC 01273(E)

Foreword, third paragraph, line 5

Changes "Messers." to "Messrs."

Page 7, first paragraph, line 1

Change "Infrared" to "infrared."

Page 7, second paragraph, line 2

Change "day and the ...." to "day and that the ...."

Page 11, third paragraph, line 2

Change "the data becomes rather ...." to "the data become rather ...."

Page 11, third paragraph, line 4

Change ".... that small holes in an otherwise continuous overcast can be detected, is important ...." to ".... that small holes, in an otherwise continuous overcast, can be detected is important ...."

Page 13, fourth paragraph, line 7

Change "These analyses using satellite observed parameters include, total cloud cover, speed, and ...." to "These analyses use satellite observed parameters including, total cloud cover, speed and ...."

Page 16, first paragraph, line 1

Change ".... the 500 mb temperatures for area and season." to ".... the 500 mb temperatures for the area and season."

Page 16, third paragraph, line 4

Move right parenthesis to include "or snow cover"

Page 22, first paragraph, line 2

Change "The major input to these ...." to "The major inputs to these ...."

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Page 25, fifth paragraph, line 2

Delete comma after "situation."

Page 31, second paragraph, line 4

Change ". . . . by Superior Allied . . . . " to ". . . . by superior Allied . . . . "

Page 33, first paragraph, line 5

Change ". . . . chart (see Fig. 3-5). " to ". . . . chart see Fig. 3-11). "

Page 42, upper portion of Figure 3-8

Add the letter "F" near $5^{O}E$, $60^{O}N$.

Page 52, lower portion of Figure 3-13

Change the "D" near $42^{O}W$, $55^{O}N$ to "A".

Page 54, upper portion of Figure 3-14

Change the "D" near $30^{O}W$, $55^{O}N$ to "A".

Page 80, second paragraph, line 2

Change ". . . . first picture, 20 October, ... " to ". . . . first picture, 19 October, ... "

Page 88, sixth paragraph, line 1

Delete comma after "equipment."

Page 94, second paragraph, line 2

Add comma after "personnel."

Page 100, third paragraph, last line

Change ". . . . 28 October 1964 (Fig. 3-38 top). " to ". . . . 28 October 1964 (Fig. 3-38 right). "

Page 114, third paragraph, line 1

Change ". . . . moving short wave is now moved . . . . " to ". . . . moving short wave has now moved . . . . "

Page 121, first paragraph, line 24

Change ". . . . to be convective cloudiness further north . . . . " to ". . . . to be convective cloudiness exists further north . . . . "

Page 125, third paragraph, line 1

Change "In the upper picture . . . . " to "In the left hand picture . . . . "

Page 127, first paragraph, line 7

Delete the comma after "operations."

Page 131, first paragraph, line 1

Add comma after "determine."

Page 135, second paragraph, line 4

Add comma after (Ref. 12). "

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Page 145, first paragraph, line 20

Add comma after "tornado."

Page 149, first paragraph, line 8

Add comma after "wind."

Page 157, second paragraph, line 5

Change ". . . . A through E in both . . . ." to "A through E (in Fig. 4-15) in both . . . ."

Page 157, third paragraph, line 13

Change ". . . . bright in Fig. _____ with . . . ." to ". . . . bright in Fig. 4-13 with . . . ."

Page 159, third paragraph, line 3

Change semicolon after "processes" to a comma.

Page 159, fourth paragraph, lines 1 and 2

Add comma after "(AVCS)" and add comma after "Section 1."

Page 160, second paragraph, line 2

Add parenthesis around "Reference 27."

Page 160, second paragraph, line 9

Add comma after "or clusters)"

Page 163, first paragraph, line 3

Change ". . . . the anvils . . . ." to ". . . . the anvil, ..."

Page 164, Figure 4-17

Change caption to read ". . . . cloud streaks in southeast flow southwest of Hudson Bay . . . ."

Page 166, third paragraph, line 5

Delete comma after "photos."

Page 170, second paragraph, line 1

Add comma after "AVCS data."

Page 170, fourth paragraph, line 12

Change "(3) will a layer of broken clouds maintain . . . ." to "(3) will broken clouds of a layer maintain . . . ."

Page 180, third paragraph, line 7

Change ". . . . pictures appear justified." to ". . . . pictures appeared justified."

Page 186, first paragraph, line 2

Change ". . . . actually represented 9.0 tenths cover, ..." to ". . . . actually represented > 9.0 tenths cover, ..."

Page 190, Table 5-5

Add to column heading "Average Percent of Observation" +C or C.

Page 193, third paragraph, lines 4 and 5

Change ". . . . satellite pictures (Ref. 35), ... " to ". . . . satellite picture, Ref. 35), ... "

Page 208, second paragraph, line 1

Change ". . . . in Section 5. 3 . . . . " to ". . . . in Section 5. 2. 4 . . . . "

Page 208, third paragraph, line 3

Change "Of the four probabilities, one that . . . . " to "Of the four probabilities, the one that . . . . "

Page 211, second paragraph, line 2

Change ". . . . that a bright area virtually unchanged in shape, from . . . . " to ". . . . that a bright area was virtually unchanged in shape from . . . . "

Page 211, fourth paragraph, line 4

Change ". . . . surface observation, to . . . . " to ". . . . surface observations, ... "

Page 215, last paragraph, line 7

Change ". . . . the Operation Guide . . . . " to ". . . . the Operational Guide . . . . "

Page 218, third paragraph, line 2

Change ". . . . prediction procedures gleaned either directly . . . . " to ". . . . prediction procedures were gleaned, either directly . . . . "

Page 221, Figure 7-2

Add large letter "A" to dark area near 43°N, 74°W.

Page 222, second paragraph, line 4

Change ". . . . and predicitions . . . . " to ". . . . and predictions . . . . "

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TECHNICAL REPORT ECOM-02173-4

METEOROLOGICAL SATELLITE TECHNIQUES FOR THE ARMY

REPORT NO. 4

CONTRACT DA-28-043-AMC-01273(E)

FINAL REPORT

1 MAY 1965 TO 30 APRIL 1966

BY

PAUL E. SHERR, JAMES C. BARNES, ROLAND J. BOUCHER, C. WILLIAM ROGERS and WILLIAM K. WIDGER JR.

JUNE 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N. J.

DA PROJECT NO. 1V025001A12601

ARACON GEOPHYSICS COMPANY

A DIVISION OF ALLIED RESEARCH ASSOCIATES, INC.

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FOREWORD

The research described in this report was performed by ARACON Geophysics Division, Allied Research Associates, Inc., Concord, Massachusetts, and was sponsored by the U.S. Army Atmospheric Sciences Laboratory (formerly the Meteorological Division, U.S. Army Electronics Laboratory) of the United States Army Materiel Command, ECOM, Fort Monmouth, New Jersey (Contract No. DA 28-043 AMC-01273(E), DA Project No. IVO25001A12601, PR and C No. 65-ELS/D-1803).

During the conduct of the contract, Dr. Donald Swingle, Mr. Irving Chernetz, and Mr. Marvin Lowenthal of the Atmospheric Sciences Laboratory have significantly assisted our studies by providing Army reports and publications which served as sources of requirements and other background data.

The authors are also directly obligated to: Dr. Arnold H. Glaser and Mr. Earl S. Merritt of ARACON Geophysics for their many and most helpful criticisms and suggestions during the preparation of this report, Mr. James Willand and Mr. Walter Smith for their assistance in data preparation for Sections 3.4 and 4.3, respectively, Messers. Claude French, James Pike, James Willand, and Leonard Hewitt, who drafted many of the figures.

Credits for individual sections of this report are primarily attributable as follows:

Mr. James C . Barnes	Sections 3.4, 4.3, and 5
Mr. Roland J. Boucher	Sections 4.1 and 4.2
Mr. C. William C. Rogers	Section 3.3
Mr. Paul E. Sherr	Sections 1, 3.1, 3.5, 6, 7, and 8
Dr. William K. Widger, Jr.	Section 2

ABSTRACT

The research discussed in this report was aimed at providing Army field units with techniques for the use of weather satellite data, especially APT (Automatic Picture Transmission) and DRIR (Direct Readout Infrared) data. The results under each of the several tasks are discussed. These include:

1. Mesoscale analysis and interpretation studies, with particular emphasis on severe local storms, squall lines, improved interpretation techniques for higher resolution (Nimbus AVCS) TV data, and cloud persistence studies.

2. An analysis of Army requirements for application of weather satellite data.

3. Case studies, which used data analogs of selected World War II and Korean campaigns. These cases were analyzed to demonstrate the utility of satellite data at the synoptic scale. In addition, a U.S. field maneuver, for which concurrent satellite data existed, was analyzed to demonstrate mesoscale and synoptic scale uses of the satellite data.

4. Investigations of methods for determining weather effecting Army operations, with particular emphasis on determining (a) sub-normal and abnormal precipitation amounts over periods of ten days and a month, and (b) snow cover anomalies.

5. The development of procedures for the field use of meteorological satellite data, with emphasis on mesoscale analyses and short-term prediction techniques.

6. The preparation of an Operational Guide.

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1. INTRODUCTION

Meteorological satellites constitute the first observing system which allows quantitative meteorological observations on a world-wide basis. It is this world-wide observing capability which offers great potential value for military meteorological requirements.

Weather has been a significant factor in Army operations for at least as far back as the historical record exists. Cases directly effecting the United States Army date from early in the American Revolution (for example, Trenton); more recent cases include D-Day in Normandy, the Battle of the Bulge, the Korean winter campaigns, and the tropical storms and monsoons of Vietnam. In Eurasia, the course of history was twice doubtless influenced by the winter-forced retreats from Russia of both Napoleon and Nazi Germany.

In spite of significant advances in some areas towards all-weather military capabilities, the need for improved weather support to Army operations has in no way diminished. This continuing need results from:

1. The ever increasing sophistication of many types of military equipment, which counteracts the parallel work directed towards decreasing dependence on environmental conditions,

2. The impossibility of making many types of Army operations (such as infantry advances and guerrilla tactics) impervious to weather conditions, and

3. The benefits that can accrue in many military situations if weather is used to advantage rather than being considered as merely a handicap.

1.1 Requirements for Meteorological Support

Meteorological support to the Army, especially when in the field, has long been complicated by such factors as:

1. The need for mobility, which limits feasible observing equipments and restricts the extent of ties to weather communications readily available in stationary facilities.

2. The frequent proximity to the boundary of the silent area deriving from enemy controlled territory.

3. The very great interest, in both space and time, in mesoscale phenomena, which are rather poorly depicted by most meteorological observing techniques (radar being until recently the prime exception).

4. The short times and limited personnel available for preparing weather analyses and operationally oriented predictions.

1.2 Applications of Satellite Data to Army Requirements

Meteorological satellites, such as TIROS and Nimbus, have clearly demonstrated that they, especially when equipped with an Automatic Picture Transmission (APT) capability, are probably the best available or foreseeable method of overcoming many of these Army weather support problems. Data acquisition for a very wide area can be accomplished with a single, mobile, van-mounted unit. Under normal conditions, the area of coverage will extend well over 1,000 miles in all directions from the location of the receiving unit, including territory under enemy control. Synoptic and mesoscale cloud patterns are vividly depicted in considerable detail. Figure 1-1 shows a mosaic of two consecutive APT pictures from ESSA 2 (an operational APT satellite). The operational grid has been superimposed so that area coverage can be demonstrated. The data are presented in pictorial form revealing both actual existing weather and nature's self-analyzed weather map. Thus, a considerable portion of the usual preliminary weather analysis chore has already been accomplished for the user who has learned how to read and interpret the satellite data.

Richards (Reference 28) has pointed out:

> "Even with the synoptic network existing in the United States, . . . (a satellite) picture provides detail and perspective which would otherwise be unattainable; to an army in the field, where conventional data might be sparse or even nonexistent, such a picture could even serve as an acceptable weather map on which major decisions might be based. One obvious example would be the selection of a cloudless area within enemy territory as the target for an airborne assault."

On the other hand, the satellite is not a meteorological panacea. It has inherent limitations which restrict the specific data it can provide. Among the inherent

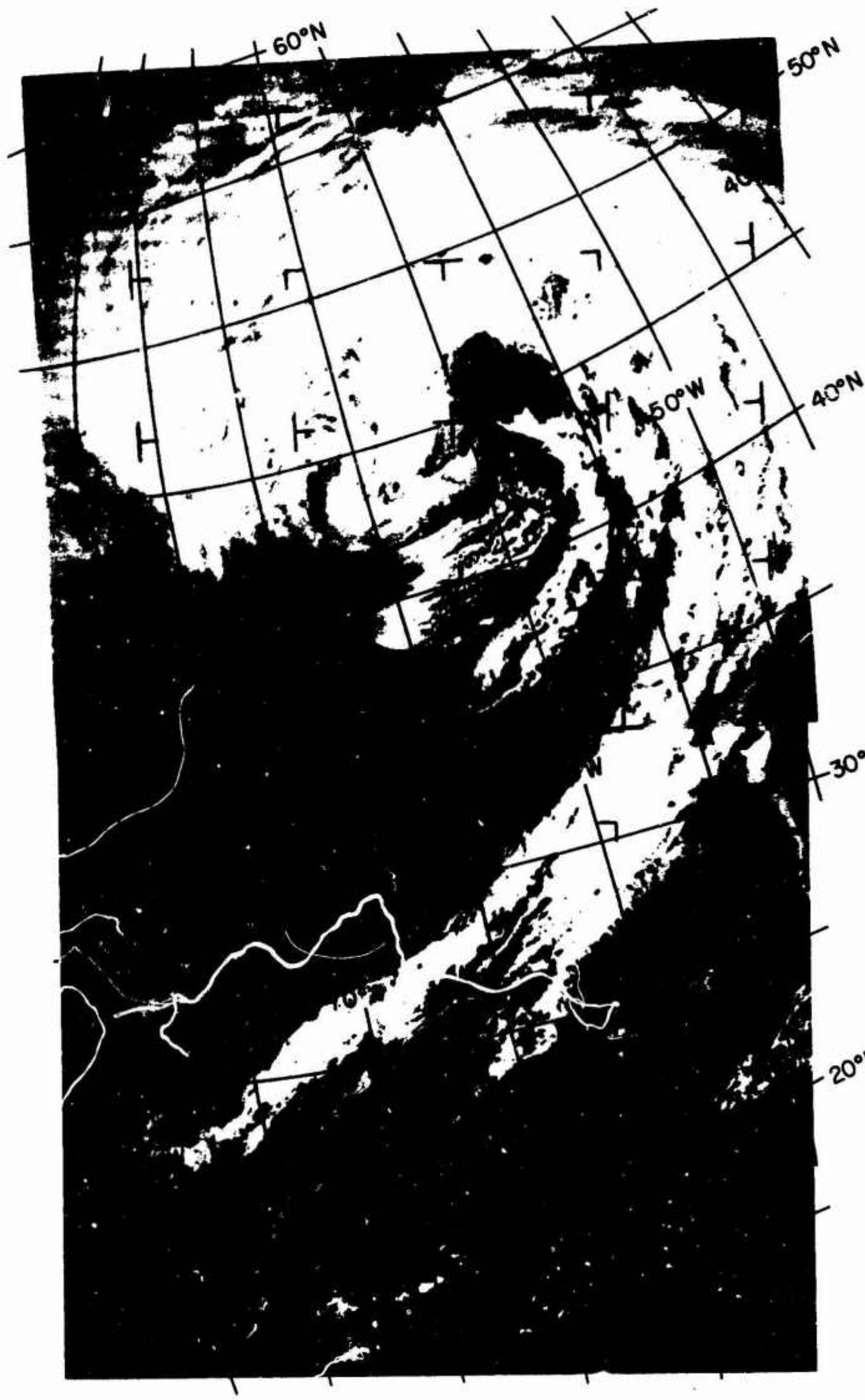

Fig. 1-1 Mosaic of Two Consecutive APT Pictures from ESSA II Demonstrating Expected Area Coverage.

limitations are the lack, in most cases, of truly quantitative data, as well as the inability to make certain types of observations. Quantitative parameters of direct military interest such as temperatures, wind direction and speed, and air densities can only be inferred. Even in the observation of hydrometeors, where the satellite excells, inferences or supplementary data are necessary within and below extensive cloud cover; this is especially true where such information as ceilings, surface visibilities, and the precise locations of areas of precipitation are needed.

1.3 Objectives and Scope

Even where there are not inherent limitations, research and development studies to date, have been inadequate in several areas crucial to Army interests, to permit optimum exploitation of the capabilities of the satellite data. Therefore, investigations were conducted (Contract No. DA 28-043 AMC-01273(E) which had several objectives. The objectives were outlined in Technical Guidelines No. 530501, Meteorological Satellite Techniques for the Army, dated 18 September 1964.

Principal objectives were:

1. Improved techniques for the identification, interpretation, and application to Army field needs of mesoscale weather phenomena observable using satellites; and

2. Preparation of an Operational Guide to provide Army field personnel with guidance in the interpretation and application of weather satellite observations.

Other objectives included:

1. Determination through case studies, of the increase in weather information to be anticipated from satellite data;

2. Identification of Army applications of meteorological satellite data;

3. Development of procedures for use of satellite data to meet field analysis and prediction requirements; and

4. Development of procedures for estimating satellite observed weather conditions affecting enemy operations.

It was found convenient to conduct these studies in terms of tasks which directly parallel the topics as described in the Technical Guidelines, as summarized below:

Task A - Mesoscale Analysis and Interpretation

A determination of the extent to which mesoscale information of value to Army operations could be derived from satellite observations. For example, the size of the observed cirrus shield associated with thunderstorm masses, was related to the probability of severe weather.

Task B - Army Requirements and Applications

Literature reviews and, as necessary, direct discussions with Army personnel were used to identify those applications of satellite meteorology which are important to the Army.

Task C - Case Studies for Army Operations Affected by Weather

Cases were studied for selected campaigns of World War II and Korea, and for a U. S. Army field maneuver within the continental United States. The purpose was to determine how a better knowledge of weather patterns as obtainable from satellite data might have been used to assist command decisions and Army operations. Analog techniques were used to relate actual operations lacking satellite data to weather situations for which such data were available. It was found that the breakdown of the blocking high (which was responsible for the prolonged bad weather near Bastogne) could have been detected from the satellite data. Mesoscale uses of the satellite data were demonstrated for the continental U. S. maneuver.

Task D - Weather Affecting Enemy Operations

Techniques were developed to permit Army use of satellite data to estimate the nature and severity of the weather to which enemy forces have been exposed. Such information is of significant intelligence value in assessing the affect of weather on the enemy's capabilities. Methods to determine integrated weather conditions over periods ranging in length from several days to a few weeks were prepared under this task. For example, techniques are demonstrated which indicate when the precipitation over an area was near, much above or much below normal.

Task E - Procedures and Techniques for Field Use of Satellite Data

Techniques and field procedures were prepared for the optimum field use of weather satellite data. This was an important task, since satellite photographs are a relatively new source of weather data, and field personnel lack experience in applying such data.

Task F - Analysis and Prediction Techniques

Interpretation and prediction procedures for using satellite data in predicting for: (1) friendly areas, (2) silent areas, and (3) single station situations were developed. Single station prediction techniques were prepared for field stations having: (1) only satellite APT data, (2) only satellite data and radar data, (3) satellite data, radar data, and a nearby rawinsonde observation, and (4) all of the above, plus limited conventional data.

Task G - Operational Guide Preparation

In addition to this final report describing the research conducted on the tasks listed above, the end products of this program include a summary technical report (Operational Guide) adaptable for use by Army and supporting personnel incorporating research advances in a comprehensive survey of meteorological satellite techniques suitable for field Army use. The Guide concentrates on providing interpretation techniques for obtaining a qualitative picture of the state of the atmosphere in areas of sparse conventional data. The applications of the weather satellite data to Army requirements are first outlined and then interpretation techniques suitable for various categories of meteorologically trained personnel are detailed. The separately bound Volume II of the Guide details orbital characteristics and procedures required for acquisition and geographical location of direct readout APT satellite data.

1.4 Data Form

Only limited amounts of data in the expected operational format (APT and DRIR*) were available for use in the research conducted under this contract.

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* DRIR is used to refer to the Direct Readout InfraRed System incorporated in Nimbus C, which has a planned launch in second quarter 1966.

Therefore, extensive use was made of satellite picture and Infrared (IR) data, many of whose characteristics are similar to the expected format. For example, data from conventional non-polar orbiting TIROS, with picture resolution of a few miles, were the main data source.

Some additional advantages of the polar orbiting ESSA 2 satellite are the data coverage over a station at the same local time each day and the pictures are obtained as the camera is pointing nearly straight down (toward the center of the earth). The APT pictures, therefore, have virtually none of the high nadir angle distortions which were common in earlier TIROS data.

ESSA 2 APT data have a ground resolution of about one nautical mile near the center of the picture. This resolution is somewhat better than previous TIROS data. To demonstrate the advantages of higher resolution data (near 0.5 nautical mile) which would be desirable for future satellites, data from the Nimbus I Advanced Vidicon Camera System (AVCS) were used. High Resolution Infrared (HRIR)* data taken during the night and presented in pictorial form were used to demonstrate the application of DRIR data to Army requirements.

1.5 Summary

The tasks reported below are reasonably self-contained and, therefore, conclusions and recommendations have been included within each individual section rather than grouping them into a single section.

However, two principal conclusions should be emphasized. First, the satellite data integrated with very limited conventional observations can provide sufficient information to prepare a weather analysis for areas where none could otherwise be attempted. A prediction is only as good as the analysis upon which it is based; hence, a higher confidence in field predictions for data sparse areas can be expected. Second, at resolutions of 0.5 nautical mile (and to a large extent at TIROS resolutions of a few miles) mesoscale features which materially effect command and tactical decisions can be observed or deduced. For example, precise boundaries of cloud masses or bands, as well as mesoscale holes, can be observed. Predictions based on persistence can be prepared for periods of a few minutes to a few hours with a high degree of confidence.

Many other operationally important weather variables can be observed. These are discussed in later sections of this report.

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* From Nimbus I.

2. THE APPLICABILITY OF WEATHER SATELLITE DATA TO ARMY METEOROLOGICAL REQUIREMENTS - TASK B

This section discusses the applicability of weather satellite data toward satisfying Army requirements for such meteorological parameters as:

a) Clouds and cloud cover, including ceilings and heights of cloud bases
b) Precipitation, including snow cover
c) Humidity
d) Pressure
e) Temperature
f) Visibility
g) Winds
h) Stability

These parameters, either directly or indirectly, can be applied to weather sensitive operational decisions such as trafficability, close air support, air mobile operations, etc.

This discussion attempts to provide an objective picture of the applications of weather satellite data to Army meteorological requirements. Because of this goal, negative as well as positive aspects have been considered wherever they are applicable.

Case examples demonstrating the value of the satellite data toward satisfying Army meteorological requirements are presented in detail in Section 3 of this report.

2.1 Types of Satellite Observations

Two classes of satellite observations are currently being obtained or are planned for immediate operational use:

1. Satellite television observations - principally for daytime use with resolutions of the order of a few tenths of miles for Nimbus AVCS (Advance Vidicon Camera System) to the order of a few miles for current TIROS and ESSA satellites.

2. Infrared observations - principally for nighttime use with resolutions of the order of a few miles.

Significant increased capabilities are expected in future years, from such advanced sensors (presently under study or development) as:

a) Infrared spectrometers or interferometers and/or microwave radiometers, able to provide vertical profiles of temperature and/or humidity.

b) Satellite television cameras with nighttime observational capabilities.

c) The essentially continuous observations of earth-synchronous satellites.

d) Sferics detectors

e) Satellite data collection systems for obtaining winds or other observations from satellite tracking of constant level balloons and/or satellite readout of automatic weather stations.

The truly unique capability of the satellite is the extent of coverage it can provide from observations made solely from a single station. The data are provided in a vivid, graphic form.

2.2 General Capabilities of Particular Note

Satellite observations provide two particularly valuable capabilities from the viewpoint of Army meteorological requirements:

a) The uniquely large area observed.
b) The degree of detail provided within the observed area.

Under typical conditions, an Army APT station will, each day, be able to observe the weather within a radius of approximately 1000 miles of the station. The number and frequency of such observations will depend on the number of APT-equipped satellites in orbit, and whether or not any of these are equipped with DRIR as well as APT. The APT ground station is a passive system and requires only a receiver. Therefore, it is immaterial whether parts of the observable area may be under enemy control, or whether there are insufficient meteorological communications between points in friendly hands. Accordingly, the satellite extends the range of radar observations by a factor of five to ten, although for somewhat different parameters and with a far lesser observational frequency. Moreover, the passive nature of the APT system is a distinct advantage over the active radar system which can easily be detected by the enemy.

A further advantage of the satellite observations is that, like radar, they present a graphic and pictorial view of the weather. In the simplest sense, areas of the existence or absence of cloud cover are readily determined from satellite data, even by persons with little or no meteorological training. Even as the skill of the interpreter increases, permitting more sophisticated analyses, the pictorial character of the data presentation remains and continues to be a significant advantage. Accordingly, the satellite data should be particularly suitable for weather briefings in the field.

In addition to providing a wider area of coverage than any other meteorological sensing system whose data are directly available to a single field station, the satellite data also provide a degree of detail that is approached by no other observational system except radar. The degree of detail is limited, in its horizontal aspects, only by the resolution of the sensing system. Existing and anticipated operational sensor resolutions are usually of the order of a few miles (seldom more than five miles), whereas those of advanced systems now under test, such as those used in Nimbus I, may be as good as a few tenths of a mile.* Accordingly, the degree of detail available is adequate to identify most or all phenomena of even small mesoscale dimensions. The satellite data are thus able to depict such variations in weather conditions as may exist between ground observational sites, and the extent of various types of conditions where the boundaries fall between or beyond locations from which ground observations are available. Depending on the frequency of available satellite observations, the data may also be able to depict the changes with time and the movements of mesoscale or larger weather features.

As will be discussed more fully below, there are distinct limitations to the parameters that can be observed by a satellite or that can be inferred from its observations. In many cases, however, when these parameters can be determined at one or more points from conventional observations, concurrent satellite data permit a determination of the areas over which such direct observations are valid. As a single example, if a station is shrouded in fog, a concurrent satellite observation will often depict precisely the area over which fog exists; without the ground observation, it would often be difficult to distinguish fog from stratus in the satellite picture (see Paragraph 3.5.3.12). On the other hand, the observation of a single station would provide little or no data on the limits of the area of fog.

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* Attainment of these improved resolutions in an operational APT mode will present serious problems, because of the more sophisticated ground station equipment that will be necessary.

Similar principles can often be applied to cloud ceilings, winds, temperatures, stability, and possibly other parameters of interest to the Army.

The remainder of this discussion will be devoted to summaries of the capability of the satellite to observe those parameters which were listed earlier and which are known to be of specific interest to the Army. During these discussions, the reader should remain aware that the amount and accuracy of the information obtainable from satellite observations is directly related to the training and experience of the personnel making the interpretation.

2.3 Satellite Cloud Observations

Cloud cover is the parameter most readily observed by a satellite. Daytime television observations will detect almost all cloudiness with three possible exceptions: (1) very thin cloudiness, especially thin cirrus; (2) scattered small clouds, usually cumulus or altocumulus, which often become clearly detectable only with resolutions better than one mile; and (3) clouds over extensive snow and/or ice. Infrared observations also provide cloud observations, which are especially useful at night, although there may at times be a question as to whether or not low clouds are present unless land features confirm the existence of a clear area. The ideal is a combination of concurrent TV and infrared observations, since the TV sees essentially all clouds and the IR provides both a nighttime capability and (at least at night, for DRIR) information on cloud top altitudes.

Satellite observations reveal directly the amount and extent of cloud cover. At resolutions of better than one mile, the data becomes rather precise on the amount of cloud cover and on the types and (by inference) the heights of clouds. The fact that small holes in an otherwise continuous overcast can be detected, is important to the Army. The number, type, and cloud amounts of multiple layers can be observed, provided of course, there are sufficient breaks in the upper layers through which the lower ones can be seen. Usually the positive detection of more than two layers is difficult. For observations with resolutions of only a few miles, cloud types can often only be inferred, rather than directly observed. The observations may underestimate the amount of scattered small cloudiness and overestimate the amount of cloudiness in broken to nearly overcast conditions.

The accuracy with which the clouds can be geographically located depends on the accuracy of satellite stabilization, and whether landmarks are visible in the picture. Typical accuracies range from errors of the order of ten miles to those no greater than the available resolution.

Perhaps the greatest weakness of the satellite observations pertaining to clouds, from the viewpoint of Army needs, is the general inability to provide quantitative information on ceilings and the altitudes of cloud bases. This is especially true in the critical range of ceilings between zero and a very few thousands of feet. With scattered to broken cloudiness, and with TV pictures with resolutions of a few tenths of miles, some reasonable estimates may be possible from the cloud types and appearances. In the more critical cases which are typically associated with overcasts, only the broadest qualitative inferences, based on general synoptic experience, seem possible. For example, it appears that fog (near zero ceiling) often has a smoother texture than low stratus (some ceiling, perhaps a few hundred to a thousand feet), and that ceilings may be locally reduced in the areas of brighter clouds, or those with higher cloud tops, within a larger field of broken or overcast cloudiness.

Where a ground observation of ceiling is available, the satellite data can assist in estimating the probable area of validity of such an observation, and perhaps in qualitative estimates of the horizontal variations in ceilings.

Some idea of the probable thickness of observed clouds can be deduced from the brightness of the clouds in the TV pictures, but the various factors influencing brightness (sun angle, satellite angle of view, drop size, equipment sensitivity and settings, etc.) are sufficiently complex to prevent quantitative inferences.

Experience has shown that while useful qualitative estimates of cloud top altitudes can often be inferred from cloud brightness (in the low resolution TV pictures), there are also many cases where such estimates may be seriously in error. Resolutions of better than one mile permit positive cloud type identification from which better estimates of cloud top altitudes can be derived. If infrared observations are available, cloud top altitudes can be observed to accuracies of the order of a few thousand feet, especially if an actual temperature sounding is available. Even without such conventional data, cloud top altitudes deduced from the IR data and climatological upper air temperature data (such as the standard atmosphere) will be useful.

The infrared data excell in providing cloud top altitudes and are entirely adequate for determining the extent (and usually the amount) of all but low cloudiness. Infrared data are inferior to the TV pictures as regards thickness estimates, cloud type, multiple layers, and inferences as to cloud base and ceiling altitudes. As mentioned earlier, the combination of IR data and a TV picture is highly desirable, since the strengths of one often compensate for the weaknesses of the other.

2.4 Precipitation

There are presently no existing or foreseeable methods for the direct observation of precipitation from a satellite. Only inferences as to the probability of precipitation are possible.

The satellite pictures and IR data do reveal specific areas (clear, scattered small cumulus, thin cirrus, etc.) where precipitation is highly unlikely. Since the probability of precipitation has been shown to increase with cloud brightness and especially with cloud top height as deduced from high resolution TV pictures or from the infrared data, it is possible to identify areas with a reasonable probability of precipitation, including identifiable cumulonimbus masses associated with severe weather. Specific studies have shown, however, that only part of an area where precipitation is probable (as determined from the satellite observations) is likely to be precipitating at any given time.

Unfortunately, the use of the satellite to determine the extent of a surface observed parameter is seldom applicable to precipitation because of the inherently great variability of precipitation in both time and area. Thus, radar observations are entirely complementary to those of a satellite.

The Army is interested not only in the existence or absence of precipitation at present and in the immediate future, but also in the overall cumulative effects of precipitation or the lack of it over the past several days or weeks as it applies to trafficability, the probability of floods, deep snow, drought, and associated dust, etc. The results of preliminary studies of these matters suggest that it will be possible to obtain useful information of this nature from analyses of cloud cover. These analyses using satellite observed parameters include, total cloud cover, speed, and intensity of storm passages over the area of interest, and the comparison of these data to the climatological expectancies for the area and season (see Paragraph 5.2).

Field applications of these techniques will be materially assisted if satellite observations over the period of interest are supplemented by the pertinent climatology, applicable soil or river characteristics, and sufficient information on soil moisture or water levels at some suitable previous time.

In addition to the application of these cumulative techniques to estimates of snow depth, the satellite can directly observe areas of snow cover in the absence of clouds, except in those regions where dense evergreen folliage masks the snow. Although care must be taken to reliably differentiate snow from clouds, this must be done in any event to determine cloud covered areas. Areas of snow cover can

usually be identified from their relatively minor day-to-day changes, as compared to the rather wide variations in cloud cover. (It is to be noted, however, that a reliable determination of whether or not clouds are present over an extensive and uniform snow cover may be difficult. Again the integrated use of IR and picture data may be used to advantage if the cloud tops are high enough for a temperature differential to permit distinguishing in the IR between the snow and the clouds.)

2.5 Humidity

Only gross inferences concerning humidity are presently possible. There is, however, a tendency for low cloud overcasts to be associated with surface relative humidities of about 70% or greater, while in clear areas or those of widely scattered low clouds the surface relative humidities will usually be less than 50%. It is to be noted that, in some regions, vertical stability or large scale subsidence may be sufficient to prevent low cloud formation in spite of relatively high humidities. However, it is very unlikely that, within the foreseeable future, satellites can provide humidity with anything approaching the degree of accuracy required for such Army requirements as calculations of index of refraction.

2.6 Pressure

Quantitative pressure information is not available from satellite observations. The cloud patterns do, however, aid in locating significant pressure features such as low centers (frequently associated with the centers of cloud vortices), surface highs or ridges, and mid-tropospheric troughs and ridges. When these inferences are combined with even a limited number of observed surface pressures or radiosonde-determined contour heights, it is possible to usefully infer areas where pressures can be expected to be above or below normal.

Studies of a limited sample of cases suggest the following relationships between the stage of development of extratropical cloud vortices and the departure from the climatological normal (for the area and season) of the central pressure or contour height.

Stage of Vortex Development	Surface Pressure Departure (mb)		500 mb Contour Departure (meters)	
	Mean	Standard Deviation	Mean	Standard Deviation
Occluding Cyclone	-18	60-100% of Mean	-150	50% of Mean
Fully Occluded, Mature Cyclone	-16	"	-180	"
Decaying Cyclone	-12	"	-120	"

2.7 Temperature

Temperature is a parameter of direct interest to many Army operations. Furthermore, the greatest contributions to density variations, which are of concern to ballistic calculations, are those of temperature variations.

The only direct satellite observations of temperature that will be available in the near future are infrared measurements of the temperatures of surfaces in clear areas. To use these, the actual observations can (and usually must) be empirically corrected for atmospheric absorption, and in ways that lead to a reasonably accurate surface air (shelter) temperature as compared to surface temperature in the physical sense.

The approximate areas of validity of either these satellite observed temperatures, or of one or more conventional surface or radiosonde temperature observations, can often be inferred from the general synoptic situation as deduced from satellite observed cloud patterns and whatever other meteorological observations are available. Even in the absence of observed temperatures, the general synoptic situation, as deduced from the satellite observed cloud patterns, and the related flow patterns provide some indication as to whether above or below normal temperatures are likely.

Improved estimates of mid-tropospheric temperatures and densities can sometimes be made using the empirical finding that the 500 mb temperature at the cold edge of a cold frontal cloud band, for certain latitudes and seasons, has an average value which is significantly different from the mean climatological 500 mb temperature for the area and season. The magnitude and sign of the average departure from the mean climatological 500 mb temperature varies with latitude and season. 500 mb temperatures estimated using these findings have root mean square errors (RMSE's) which are about equal to the climatological standard deviations of

the 500 mb temperatures for area and season. In specific months and for favorable conditions where the synoptic situation can be clearly identified from the satellite pictures, the RMSE of the 500 mb temperature, estimated from these findings, may be reduced to one-half of the RMSE when the 500 mb temperature is taken as the climatological value for the month and area.

Another approach to temperature determinations uses the differences in the (2.5^{o} averaged) TIROS Channel 2 (8-12 μ) temperatures between the warmest (presumably clear) areas on opposite sides of a major cloud band. These differences were found to be representative of the 500 mb temperature differences (as obtained from conventional data sources) between these two areas. Although the specific comparisons to date were usually at the 500 mb level, the vertical variations in large scale temperature gradients in the mid-troposphere are usually small, and these results are probably equally valid for inferring temperature gradients at other mid-tropospheric levels.

2.7.1 Frozen Water Surfaces

Since the freezing and thawing of bodies of water are primarily related to temperature, this topic is most conveniently discussed here. The satellite pictures often show whether bodies of water are frozen. However, it is often difficult to differentiate thin or smooth ice (prior to wind roughening) or snow cover from unfrozen water. Furthermore, except as partially unfrozen areas may be detectable, the pictures provide no indication of the thickness or strength of the ice.

2.8 Visibility

In most cases, the satellite data provide no direct, reliable information on visibilities since apparently hazy areas may be due to haze well aloft, thin cirrostratus, scattered small cumulus, or even equipment responses. An exception may exist if a plume of pollutant is clearly visible and can be identified as such from its relation to a logical source.

While there is usually no way to infer visibilities below satellite observed clouds, as discussed earlier, the satellite data may be used to estimate the probable area of reduced visibility when a ground observation is available (an example would be a ground observation from within a satellite observed cloud patch).

In a few cases the probability of areas of reduced visibility can be reasonably inferred, although no precise estimates of the actual visibilities or of the area of reduced visibility are feasible. A good example of this is the high probability of reduced visibilities under a satellite-observed, severe storm cumulonimbus mass.

In a few other cases, such as valley fog or coastal stratus, it is often possible to deduce a high probability of low or reduced visibility.

2.9 Winds

Wind directions can often be inferred from the cloud patterns, especially when resolutions are better than one mile. With such resolutions, cloud streets can be differentiated from billow clouds and lee waves. Furthermore, first order cloud streets (those of closest spacing, not usually visible with resolutions of only a few miles) can be seen; usually first order streets will tend to be aligned with the low level wind as well as the shear, while this is less probable for cloud streets of second or higher order. No methods for estimating wind speeds from cloud streets have as yet been determined.

From cloud streets alone, there will be at least an ambiguity of 180° in wind direction. This can often be resolved, in areas where the flow crosses a coast or the shore of a significant lake, from the displacement of the edge of the cumulus field relative to the coast line. The general synoptic pattern as deduced from larger scale aspects of the cloud patterns can also aid in resolving such an ambiguity.

Where lee waves or billow clouds can be identified, the wind will usually be perpendicular to the cloud line orientation. Directional ambiguity for lee waves can be resolved from the relation of the clouds to the topographic feature creating the flow disturbance, and some estimates of the mean wind speed in the mid-troposphere can be made from the spacing of the wave clouds. In the case of billow clouds, no specific keys to resolving the directional ambiguity are available.

The wind velocities in tropical storms, hurricanes, and typhoons can be estimated from the size and character of the clouds associated with the storm.

Variations of the wind with altitude may be depicted in one of two ways:

1. The direction of cirrus anvil plumes, which tend to parallel the shear.

2. Jet stream cirrus bands, which parallel the jet stream and typically lie just on the equatorward side of the jet stream core.

The overall cloud pattern will often permit the approximate flow pattern at the synoptic scale to be deduced. While this is particularly true for the general flow pattern at the 700-500 mb level, useful inferences as to the low level flow pattern are also frequently possible. When one or more specific surface or rawinsonde wind observations are available, the general pattern inferred from the satellite observations can be used to estimate the extent of the area over which such an observation will be valid; for example, an observed southwest wind can be expected to shift to west or northwest when crossing a cold front.

2.10 Stability

While the satellite data do not provide quantitative information on lapse rates, the existence of relatively stable lapse rates can be inferred where fog or stratus is observed, and of steeper lapse rates as the clouds assume more of a cumuliform character. When the individual cumuliform masses are isolated or are within a general area of scattered to broken cumuliform clouds and are observed to be of cumulus congestus or cumulonimbus size, lapse rates near dry adiabatic can be inferred through a significant part of the lower atmosphere. (When cumulonimbus clouds form a more or less continuous line, or are imbedded in a frontal cloud band, they may result from large scale lifting, with the layer of instability existing only at levels well above the surface. The ability to infer atmospheric stability increases significantly when pictures with resolutions of a few tenths of a mile are available. For example, the depth of the layer of overturning will usually be about one-half the spacing between first-order cloud streets. To the extent that the cloud-forming process can be inferred (from high resolution TV pictures), the atmospheric structure and its stability may be deduced (see Paragraph 4.2.2.4).

2.11 Severe Storms

Severe local storms, typically accompanied by heavy rain showers, thunderstorms, hail, and damaging winds, can often be identified from the associated large cumuliform cloud masses which are very bright (in TV pictures), with sharp edges and often a surrounding area of suppressed cloudiness (see Section 4.1). In infrared data, the cold high cloud tops aid in identifying these systems.

2.12 The General Synoptic Situation

While the Army staff officer or commander is most interested in the details of the current weather in his immediate area of responsibility and over adjacent enemy-held areas, and the conditions and changes to be anticipated in the next few hours, he is concerned also with weather conditions to be anticipated within the next day or so. Significant information can often be deduced from the satellite data, since, as discussed above, the satellite data typically will depict the situation out to a radius of 1000 miles in all directions, regardless of whether individual parts of this area are in friendly or enemy hands. Such weather systems as cold fronts, existing or developing storms, extensive clear areas associated with high pressure areas, etc., which may be approaching the area of responsibility can be detected, even in the absence of other sources of data (as when the weather is moving in from enemy-held territory, see Section 3). General aspects of the conditions to be anticipated can be inferred from the identification of common synoptic systems, while details and deviations from the most typical patterns are often revealed directly in the satellite-observed cloud patterns. In particular, the satellite data may reveal significant deviations from climatology for particular areas or periods of time.

An excellent example of this type of application of satellite data can be derived from problems encountered by Army meteorologists in the World War II Italian Theatre. Many storms affecting Italy generate in the Gulf of Genoa, and the only source of information on such developments was pressure falls in northern Corsica (since northern Italy and France were under German control). The APT system would have permitted a daily surveillance of the amount and organization of clouds over the Gulf of Genoa, and positive detection of storm formation and deepening. Many parts of the world have their own similar critical areas, often adjacent to a coast, where storm formation frequently takes place.

In several respects, the satellite data are far superior to the radar observations for the purpose of determining the general synoptic situation. While they lack the frequency of the radar data and cannot absolutely detect precipitation, they cover a far greater radius about the station and so may extend well into enemy held territory and, furthermore, cloud patterns are often more persistent and representative of the general synoptic situation than are precipitation. This is not to say the radar data should be disregarded; Army personnel should make optimum use of all sources of available information (conventional ground observations, radiosonde data,

radar, aircraft reconnaissance, satellite, and others) in determining both existing and future weather conditions effecting their area of responsibility.

It is to be emphasized that these types of information can be used not only to determine the current situation, but also the conditions to which an enemy has been exposed during the past few days.

A further application of meteorological satellites derives from the frequent requirements established by Army commanders for long range (five days or longer) planning predictions. Field weather units are seldom qualified by either experience, number of assigned personnel, or available data to prepare such predictions. Developments now in progress are expected to augment the satellite portion of the APT system to permit transmissions of facsimile weather charts (WEFAX) between APT pictures and without loss of significant APT coverage. This capability could be used to disseminate five-day (or longer) prognostic charts prepared by the National Meteorological Center.

3. CASE STUDIES OF ARMY OPERATIONS AFFECTED BY WEATHER - TASK C

This task had as its general purpose, the demonstration of how satellite data could have been used to advantage by Army personnel and/or supporting meteorologists in determining and forecasting weather situations which have affected Army operations.

3.1 General Introduction

Three cases were chosen for study. These include: (1) a major campaign of World War II, (2) Korean Autumn Campaigns of 1950 and 1951, and (3) a major field maneuver within the Continental United States. Concurrent satellite data were not available for the first two cases because the first meteorological satellite was not launched until April 1960. For these cases, a careful study of the prevailing weather situations (synoptic conditions) was made, and weather analogs were chosen from periods after 1960 when concurrent satellite data were available. Unfortunately, none of the researchers participating in this study had on-the-spot knowledge of forecast problems or of command decisions which were weather dependent. However, the researchers knowledge of similar weather critical operations and documentation of the selected cases has been used in the preparation of these cases.

Weather, by its very nature, is a continuously changing process and thus no two situations over the same place during any reasonable time period will be exactly the same. Accordingly, even though good analogs can be chosen which duplicate particular weather conditions at a given locale, a case should be included for which concurrent satellite data are available. The third case studied describes a large air-mobile maneuver in the central United States for which good satellite data, good conventional weather data, and good documentation exists. The chosen maneuver was "Operation Gold Fire I," Ft. Leonard Wood, Missouri, held during late October and early November 1964.

3.1.1 Satellites as an Observational System

One of the unique capabilities of meteorological satellites is their ability to provide observations from areas over which earth based observations are lacking. Generally, these areas are data sparse areas such as over oceans or enemy controlled territory. However, with a moving battle area or a fluid battle zone such as in Vietnam, a lack of good surface and upper air observations is most probable because communications difficulties, danger from guerilla activity at remote stations, etc. may preclude obtaining these data. Thus, the satellite data, integrated with whatever conventional meteorological data are available (including weather and surveillance radar data) can provide a better knowledge of weather patterns which are of extreme importance to the Army. In addition, when the existence of weather patterns such as fronts have been established by conventional data, the distributions of cloudiness associated with the fronts can be better specified using satellite data than by any other means available in the field. It is the distribution of such cloud and precipitation patterns on a scale not larger than a few hundred miles that is important to Army operations. For example, the positioning of a front on a weather map does not reveal whether the areas of clouds and precipitation are (1) distributed along the front, (2) ahead of the front, or (3) behind the front. This can only be determined from a very dense ground network or from a good radar which can at best define the precipitation areas. The satellite can present a pictorial description of these distributions and can precisely locate the boundaries or edges of the cloudiness so that more precise (especially short term - two to three hours) predictions can be prepared.

3.1.2 Meteorological Interpretation of Satellite Data

Present day meteorological observations are largely tailored to the needs of numerical weather prediction by high speed computers. The major input to these numerical computations are hemispheric contour charts, prepared at central data processing centers. The major use of satellite data in preparing this input has been to provide and improve contour analyses in regions of sparse data, mainly oceanic areas (References 3, 19, 20, and 29). Since this type of demonstration of the value of satellite data is already being carried out and is not directly within the Army purview, we will not undertake such an effort here. Instead we will concentrate on providing a qualitative picture of the state of the atmosphere in areas of sparse data.

In view of the trend toward computer type forecasts, one may ask of what use is a qualitative picture of the state of the atmosphere. In spite of the computer outputs, man is still needed to interpret and evaluate these results for specific problems and to prepare a prediction in the language of the user. The meteorologist does not perform these tasks in a vacuum; instead he must become oriented as to how the atmosphere is behaving. One such orientation procedure had been discussed recently by Houghton (Reference 18). Houghton states,

> "When the forecaster comes on duty he first studies the behavior of the atmosphere over a large area and for the past few days and acquaints himself with the current pattern of change and development. He looks at the broad-scale features such as the positions of the troughs and ridges of the long wave pattern...."
>
> "The analysis and presentation of the data must be such that the forecaster can study both the large-scale evolution of the atmosphere in terms of the troughs and ridges and other features of the long wave pattern and the finer details of small scale features, which move within and are largely controlled by the general circulation."

Normally, the meteorologist becomes oriented by recognizing the various synoptic entities, such as troughs and ridges, in the contour and wind fields. One purpose of these case studies is to demonstrate that in the absence of contour and wind data, such as over enemy-held territory, interpretation of the satellite data

can provide orientation for users through specifying positions of synoptic entities such as troughs and ridges. In a third case, the subsynoptic-mesoscale features of the integrated conventional and satellite data are treated in detail.

3.2 Synopsis of Case Analyses

The case studies are presented in detail in Sections 3.3, 3.4, and 3.5 below. Synoptic case studies, by their inherent detail, require a comprehensive and detailed reading for complete appreciation. Therefore, a few of the more salient observations and conclusions are summarized here.

3.2.1 Battle of the Bulge

The weather associated with the Battle of the Bulge was characterized by a blocking situation, which greatly reduces the normal west to east movement of weather systems. It characteristically produces extended periods of consistently good or bad weather, depending upon one's location with respect to the blocking high pressure area.

Prior to and during the Battle of the Bulge, two weather considerations were critical.

1. The Germans needed a prolonged period of bad weather to neutralize the Allied air superiority to allow them to launch a counterattack.

2. The Allies, after the battle was joined, needed good weather to use their air superiority for tactical support and resupply.

Analysis of the best satellite analog that was available shows that the satellite data would have been of immeasurable help to the Germans (in this case the side most needing silent area data) in assessing the weather patterns in the Atlantic. In particular, a rather good estimate of the mid-tropospheric flow pattern (that near 20,000 ft. altitude, the weather controlling factor in this situation) and its evolution with time into a blocking situation can be made from the satellite data. Thus, satellite data would have provided the information that was needed for making a forecast of a prolonged spell of bad flying weather in the battle zone.

Near the end of the analog period, satellite data over the Atlantic (the silent area from the German viewpoint) indicated a return to more normal west to east motion of weather systems. This information would have alerted the Germans to

future periods of good flying weather, and of increased attack by the Allied air forces. In the actual Battle of the Bulge, the advent of attack by Allied aircraft required that mass movements of German troops be restricted to night, rather than by day as earlier. Decisions to adopt night movement tactics, and preparations for carrying them out, would have been aided by field forecasts of clearing weather, which the satellite data would have permitted.

For the friendly area (the Allied viewpoint), the satellite data would have added another type of vital data to the other evidence indicating good flying weather was coming and that air support and resupply missions should be ready to go. In addition, a tactical decision by the Allied field commanders defending Bastogne to prepare camouflage suitable for use with bright snow cover conditions (required when clearing occurred) would have been aided by field forecasts, utilizing satellite data, of imminent clearing.

3.2.2 Korean Autumn Campaigns

The Korean conflict placed the Allied armies in the position of having important weather producing systems moving into the combat area from the meteorologically silent, enemy-held territories to the west and northwest.

During the late summer and autumn of both years of the conflict, operations were seriously affected by weather situations which limited artillery and air support, paratroop operations, etc. Analyses and predictions for these weather situations were inadequate because they were prepared from minimal conventional data.

The first satellite analog that was selected, for 2 to 5 October 1964, indicated that a weather producing system, principally associated with a mid-tropospheric disturbance, was clearly depicted in the satellite data. This system could have been detected while still over enemy held territory (see Fig. 3-18). Accordingly, its movement could have been delineated and subsequent forecasts of cloud cover and of precipitation could have been made under conditions where it would have been difficult, if not impossible, to do so without the addition of the satellite data. A knowledge of the sharp rear boundary of the cloud cover, as defined in the satellite pictures, would have allowed bombing and reconnaissance operations to be resumed hours before they might have been scheduled in the absence of the satellite data.

The second Korean analog, for 15 to 17 October 1964, provided an example of another situation which would have presented Army personnel with a difficult forecast problem. A frontal cloud band was observed in the satellite pictures as it

moved across Korea. A broadening of the band over the peninsula (see Fig. 3-28) could be related to subsequent storm development, but such development would have been virtually impossible to forecast from only the limited surface observations. Breaks in the band, which would not have been determined even with present conventional data coverage in Korea, were detected in the satellite pictures.

The third Korean analog, for 20 to 21 October 1964, exemplifies a rapidly moving weather system which produced significant precipitation over a large part of Korea. These rapidly moving situations are difficult forecast problems even when good conventional data exist and present the forecaster an impossible task in most combat situations. This system could be detected well up wind of the peninsula and tracked across Korea, using the satellite data (see Fig. 3-29).

3.2.3 Maneuver in Continental United States

A relatively well documented field maneuver was chosen with the help of personnel at Hq. USCONARC, and has been used to provide a case with concurrent satellite data. This maneuver, nicknamed "Operation Gold Fire I," tested joint Army-Air Force air mobile techniques utilizing both fixed wing and rotary wing aircraft.

This case demonstrated several advantages of the use of satellite data. As in the previous cases, emphasis is placed on showing that, in the absence of contour and wind data, the satellite can provide forecasters with good estimates of the wind and pressure patterns. In addition, several analysis techniques, including those developed under the present contract, are illustrated. The discussions emphasize forecast problems over areas ranging from a few miles to a few hundred miles in size.

It has been definitely demonstrated that the integration of the satellite data with whatever conventional data can be obtained in a field situation, leads to improved descriptions of the state of the atmosphere, and to better forecasts of such operationally significant parameters as the precise location of the boundaries or edges of cloud bands or masses, the amount of area covered by cloud, and the cloud patterns from which precipitation is likely to be falling. In addition, mesoscale features important to Army operations such as (1) the identification of small scale cloudy and clear areas (see Fig. 3-50), (2) short term cloud persistence revealed by two or more satellite passes over the same area (see Fig. 3-45), (3) the presence of cumuliform cloudiness over mountains or hills suggesting instability and convective

turbulence (see Fig. 3-45), and (4) a knowledge of low level wind direction revealed by position of cloudy and clear areas relative to terrain features, have been demonstrated to be obtainable from the satellite data (see Fig. 3-47).

3.3 Phase 1 - Analog of World War II Campaign

3.3.1 Introduction to Case Study - Battle of the Bulge

An examination of satellite observations showed that a weather situation analogous to that for the Battle of the Bulge could be found. This is fortunate, because the Battle of the Bulge is well documented, well known by Army personnel, and need not be described here.

In the Battle of the Bulge, the two most pressing weather considerations were:

1. The Germans needed a prolonged period of bad weather to neutralize the Allied air superiority during the counterattack.

2. The Allies, after the battle was joined, needed good weather to use their air superiority for tactical support and resupply.

Analysis of the satellite analog shows that the satellite data would have been of immeasurable help to the Germans (in this case the side most needing silent area data) in assessing the weather patterns in the Atlantic. In particular, an estimate of the 500 mb flow pattern and its evolution with time into a blocking situation can be made from the satellite data, thus giving the Germans much needed information for making a forecast of a prolonged spell of bad flying weather in the battle zone.

3.3.2 Synopsis of Weather in Battle Area

The actual surface weather occurring during the battle is outlined in Figure 3-1. The sources for this reconstruction were the Northern Hemisphere daily weather map series (References 9) and Reference 4. The daily weather map series gives surface observations for once a day, at 1230 GMT. The reports available near the battle area were Amsterdam, Paris, Reims, and Frankfurt am Main. These reports were sporadic during the period 15-25 December 1944. But using these reports and weather descriptions from Reference 4, the surface weather in the battle area was constructed. The weather in the battle area consisted of a

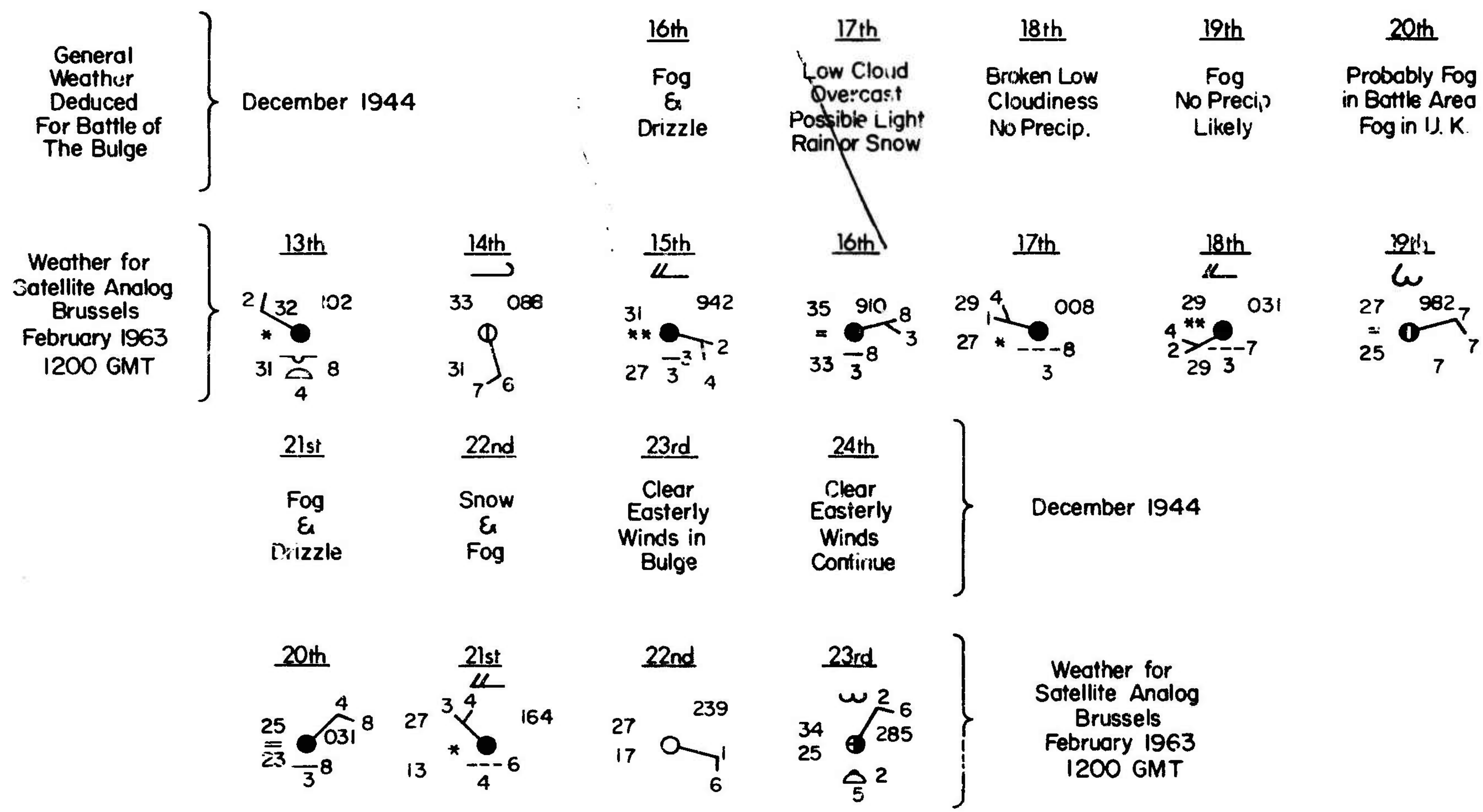


Fig. 3-1 Schematic Outline of Daily Weather in Battle Zone During December 1944 and the Daily Weather at Brussels During the Analog Case of February 1963.

seven day period of fog, low cloudiness, and intermittent periods of precipitation, with clearing occurring on the eighth day.

The surface weather for the analog (1963) case is also shown in Figure 3-1, based on once a day reports (1200 GMT) from Brussels (Reference 10). The analog period has a similar seven day period of low cloud, fog, and precipitation, with clearing on the eighth day.

The 500 mb chart for one observation time during the actual Battle of the Bulge period is shown in Figure 3-2. The 500 mb flow during the period was characterized by a blocking situation, with the principal blocking high located over western Russia and cyclonic flow in the battle area. This 500 mb pattern is typical of prolonged periods of bad weather.

The 500 mb chart for an observation time during the satellite analog case is shown in Figure 3-3. The contour pattern is typical of the analog period and shows a blocking situation affecting western Europe but with the principal blocking high located over the eastern Atlantic rather than over western Russia. However, the similarity of the weather in the battle area for both periods is extremely good as shown in Figure 3-1. Furthermore, lesser blocking highs were present in the areas of the principal highs, increasing the degree of similarity.

For an effective counterattack, the Germans needed a blocking situation to insure a prolonged period of bad flying weather. In the satellite analog, the blocking high developed in what was enemy-held territory for the Germans. Therefore, the satellite analog case will be analyzed principally from the German point of view, which examplifies the silent data area use of the satellite data. Both the formation of the block for the launching of the attack and the breakdown of the block permitting the introduction of Allied air power into the battle, will be considered from the German viewpoint.

3.3.3 Summary

A common weather pattern which would produce the required prolonged period of bad weather is a blocking situation. In the satellite analog, the blocking high is found in the enemy-held territory of the eastern Atlantic. The onset of this blocking situation was deduced from the satellite observations of the development sequence of a cyclonic system in the eastern Atlantic. The continued existence of the blocking

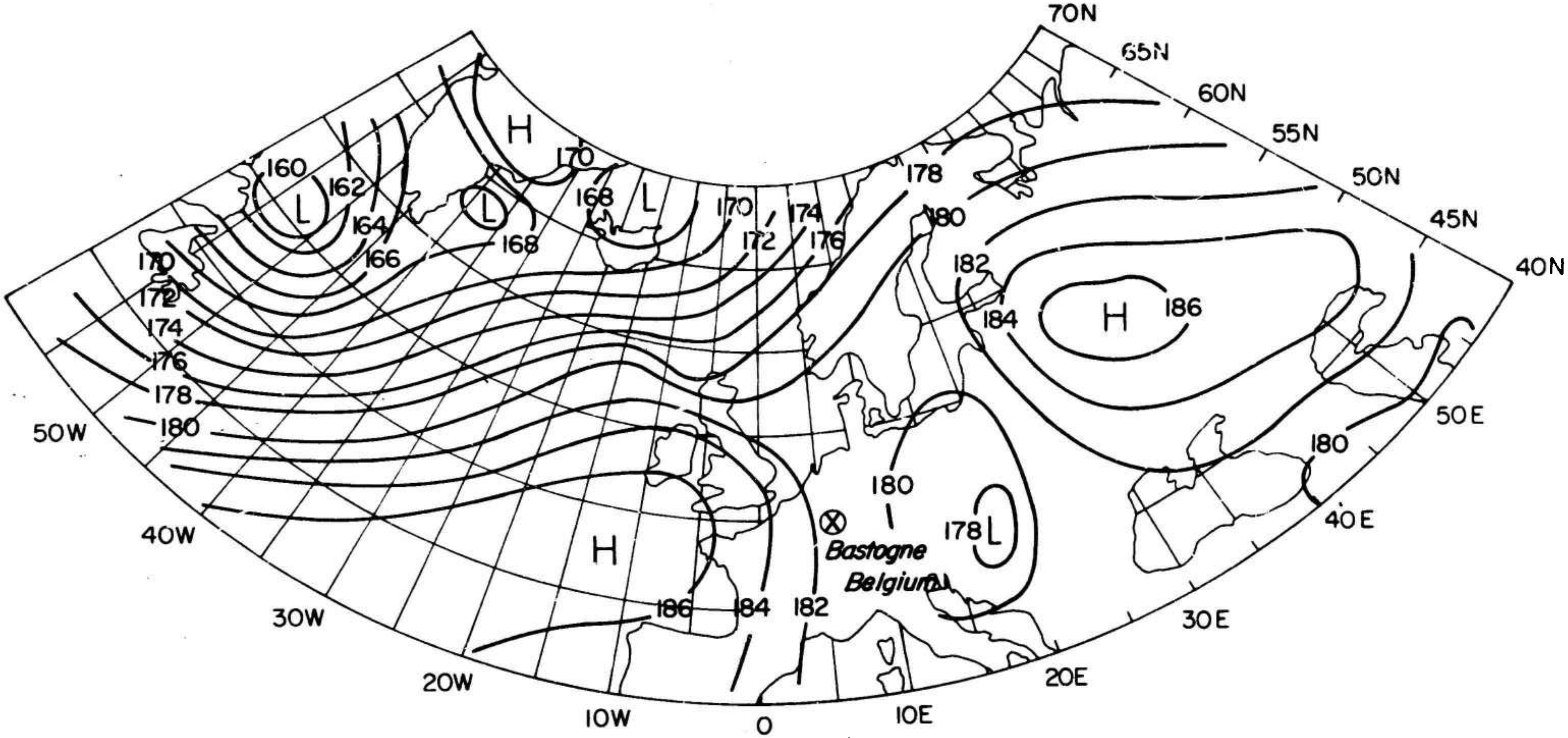


Fig. 3-2 500 mb Chart for 0400 GMT, 21 December 1944.

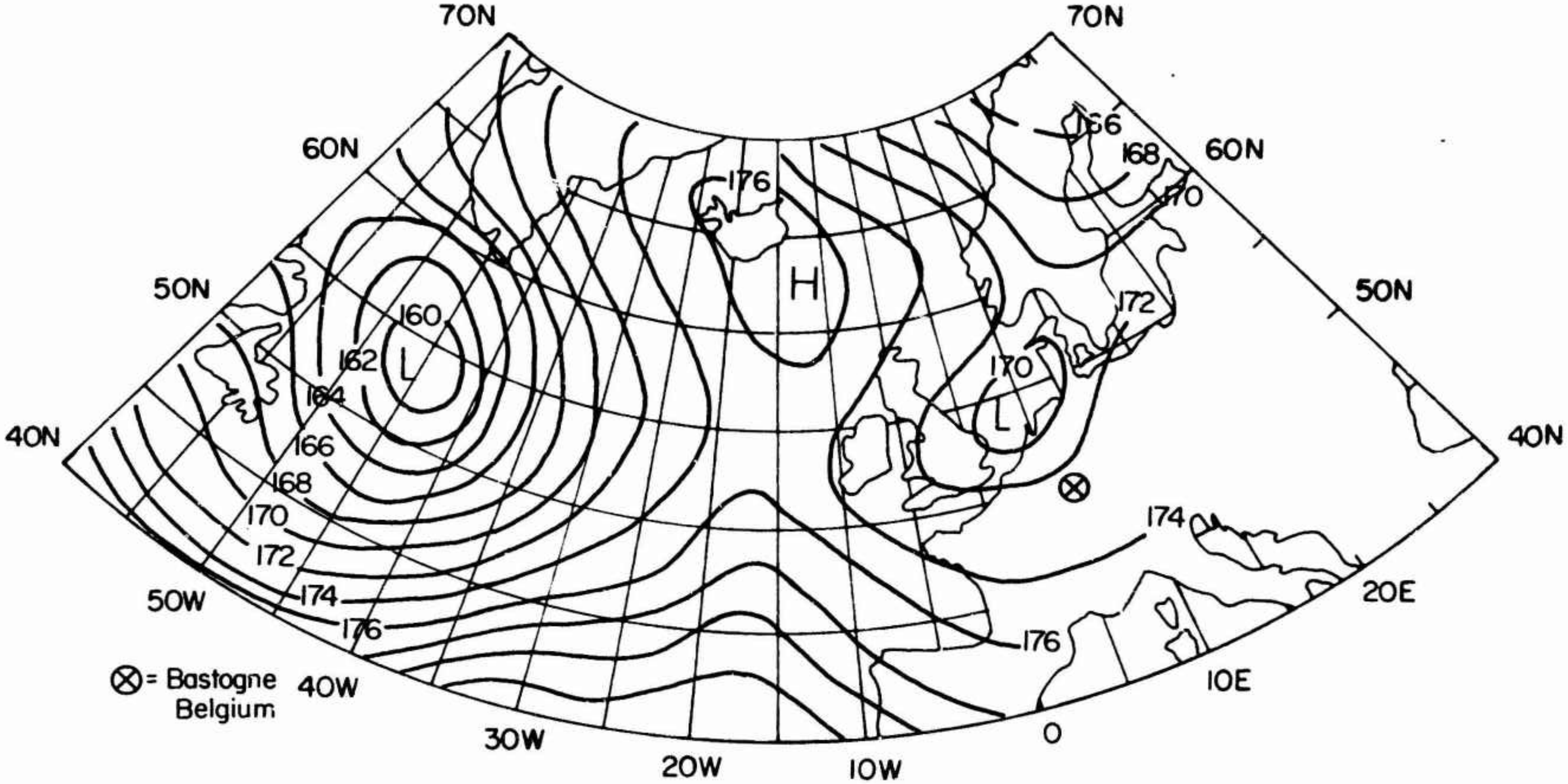


Fig. 3-3 500 mb Chart for 1200 GMT, 17 February 1963.

situation was deduced from the development and maintenance, over many days, of a large longitudinal "clear" area and from the quasi-stationary character of the cyclonic system in the eastern Atlantic.

The breakdown of the block and the return of conditions indicating a probability of good flying weather was important to the Germans. With the onset of clearing weather, the Germans had to resort to mass troop movements at night (Reference 4) to avoid renewed attack by Superior Allied air forces. Onset of the breakdown of the block in the analog case could be deduced from the re-establishment of normal west to east storm movement across the Atlantic at the latitude of the block. This state was deduced, using the satellite data, from the appearance of overcast to broken middle and/or high cloud synoptic scale cloud systems in regions where they had been absent during the blocking period; and from the regular west to east movement of these systems from one day to the next.

3.3.4 Presentation Form of Satellite Data

For this case, the satellite data will be presented mainly in the form of nephanalyses, prepared from satellite TV pictures taken near 1200 GMT for each day of the period. The nephanalysis format was adopted for the following reasons:

1. A large geographical area can be viewed at one time so that the areal continuity of a single system and the relationships of different systems to each other can be seen. This is required since the analog is based on TIROS V and VI data which were in non-polar orbits. Future APT satellites will be in polar orbits and problems of nadir angle and coverage of non-polar orbits will be eliminated.

2. On some of the days, three satellite passes viewed the same geographical area in the space of a few hours. The nephanalysis provides a single data presentation for all these observations and reduces any confusion which might result from three different views of the same system.

3. Preparation of the nephanalysis allows the reader's attention to be concentrated only on those cloud fields which are deemed important for deducing the state of the atmosphere for this case.

A few satellite pictures have been included where needed. For example, the picture which has been depicted in Figure 3-4 is shown in Figure 3-5.

In preparing the nephanalyses, synoptic scale overcast to broken middle and/or high cloud areas associated with cyclonic systems were emphasized. Small scale, patchy overcast to broken middle and/or high cloud areas, and overcast to broken low cloud areas which are usually not important in the determination of the gross synoptic patterns were not usually delineated. Discussions of local weather in the battle area, of course include this type cloudiness. For convenience in the following discussion, areas devoid of overcast to broken middle and/or high cloudiness will be called "clear." Areas with no cloud visible will be called absolutely clear. Differentiation between cloud types and determination of those cloud areas which are synoptically important are based on techniques contained in Reference 35 and the writer's experience.

3.3.5 Qualitative Description of the Weather From Satellite Data

This section will present a qualitative description of the atmospheric systems as deduced from satellite pictures. First, a short summary of these weather descriptions and their relation to the battle analog will be presented for those readers not interested in the technical details of interpretation of satellite data. Following this, a more detailed description of how these qualitative weather patterns were deduced from satellite data is presented.

3.3.6 Discussion of Analysis Techniques

This technical presentation will show what a trained meteorologist, experienced in the use of satellite data, can deduce about the state of the atmosphere by interpreting satellite data alone. This analysis is not designed, per se, to train meteorologists to interpret satellite data. Training material can be found in Reference 35 and the Operational Guide.

The technical presentation for each day will consist of the following parts:

1. A general synopsis of the atmospheric state in terms of the 500 mb and surface systems, with emphasis on the 500 mb level.

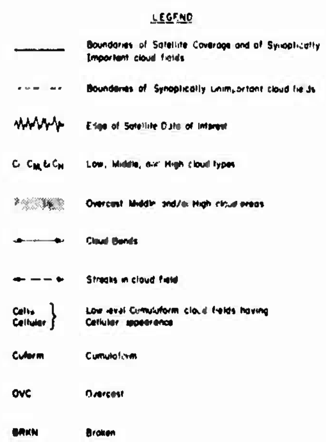
2. A discussion which will present the reasoning by which the synopsis is deduced from the satellite data.

3. The contours from the NMC operational 500 mb chart for the area and time, to allow the reader to evaluate the deductions that were made from the satellite data alone.

The 500 mb chart and the nephanalysis will also allow the reader to examine how the contour analysis might be amended in sparse data (friendly) areas. As mentioned previously, analysis modification is outside the primary scope of the present work. However, as an example, one analysis modification will be outlined for a 500 mb chart (see Fig. 3-5).

An important point of procedure for the silent area case study was that the estimation of the synoptic state from the satellite data was made with almost no knowledge of the analyzed contour patterns. The general overall pattern was known because the analyst was involved in the original case selection. However, enough time had elapsed between the original case selection and the analysis of the satellite data so that exact locations of systems, their stages of development, and the locations and character of wind fields were not known. The deduced atmospheric state is then the closest to one deduced from satellite data alone that could be obtained within the case selection scheme employed.

Legend for Nephanalyses in Section 3.3



3.3.7 Detailed Discusssion of Analyses

11 February 1963

Figure 3-4 presents the satellite data for 1519 GMT from orbit 3402, TIROS V. The satellite data leads to the following deduction, as discussed in detail in the next paragraph. A low pressure system, probably closed off from the surface up to and above 500 mb, is located near A. A 500 mb ridge lies N-S through B. The 500 mb flow is southeasterly along CC' and east northeasterly along C'C". A low pressure system is located just east of the eastern end of the satellite data.

The vortical cloud pattern south of Greenland indicates a low pressure system is located near A. The hooked, streaked portion of the vortical cloud band located southeast of A indicates that the system is closed off at and above 500 mb. The area void of middle and high cloud around B suggests a 500 mb ridge N-S through B. The streaky cloud band oriented northwest-southeast parallel to CC' and the ridge position at B, suggest southeasterly winds along CC'. The cloud band north of C'C", the streaky cloud bands south of CC', and continuity with wind direction along CC' suggest east-northeasterly winds at 500 mb along C'C". The cloud area at the eastern edge of the satellite data area is the western edge of the cloud field associated with a low pressure area east of the satellite observation area.

The actual 500 mb map (Fig. 3-4) indicates a major low pressure system is located further west near 63W at 1200 GMT. A trough extending east-west south of Greenland through A, has been indicated based on very meager conventional data. A closed 500 mb center could easily be located near A at 1200 GMT and might well be very near A by 1500 GMT. Thus, the deductions made without reference to the conventional chart are valid.

Pictures upon which the top of Figure 3-4 is based, are shown in Figure 3-5. These are presented so that the reader can be aware of the types of data from which the nephanalyses were constructed.

12 February 1963

Figure 3-6 presents the satellite data for 1442 GMT from orbit 3414V. From continuity and the satellite data, one could deduce the following synoptic situation:

A quasi-stationary 500 mb and surface low at A.

A cyclonic system moving east onto continental Europe at about 3° of latitude per day.

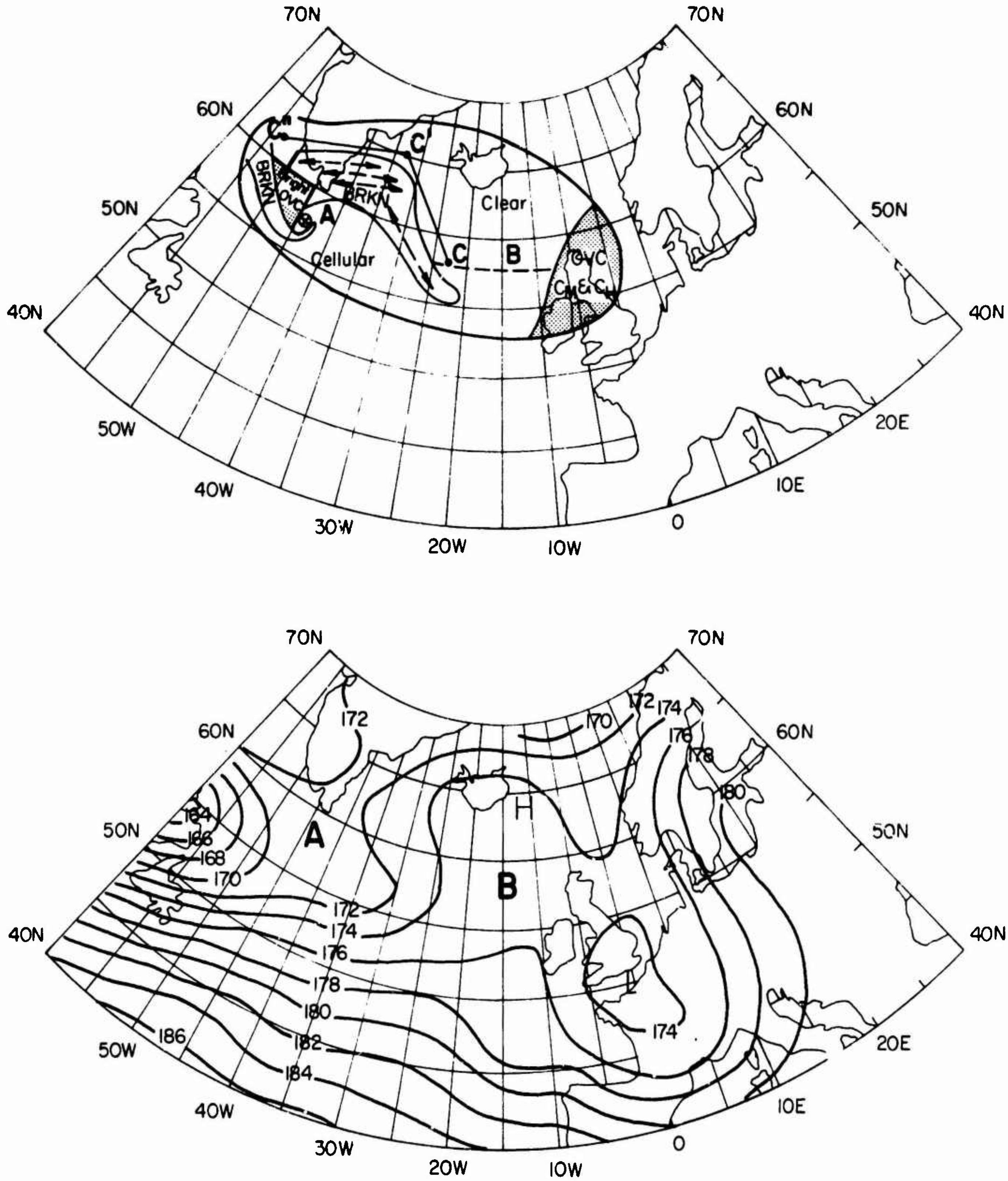


Fig. 3-4 Schematic Nephanalysis (upper) 1519 GMT and 500 mb (lower) 1200 GMT, 1! February 1963.

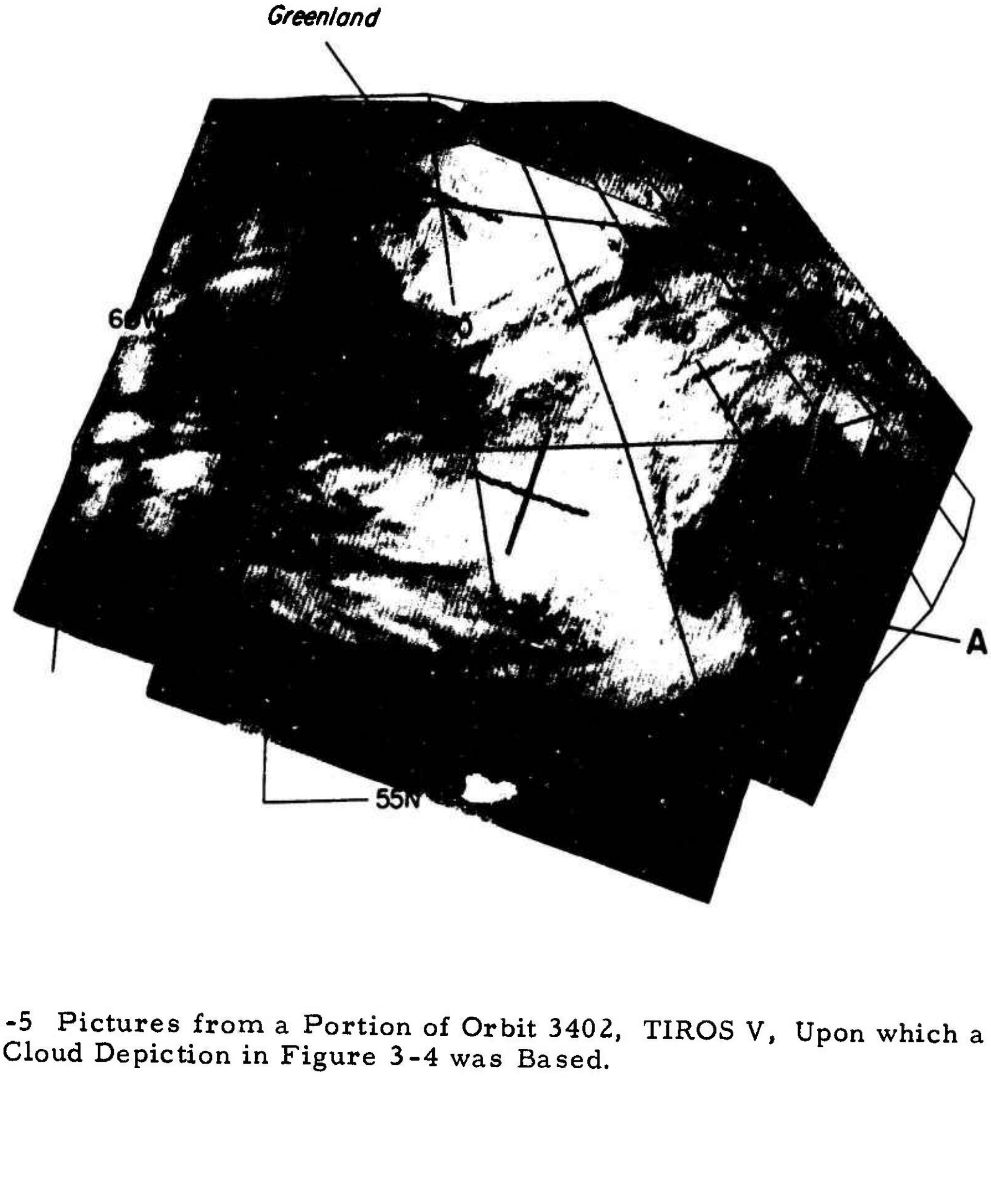


Fig. 3-5 Pictures from a Portion of Orbit 3402, TIROS V, Upon which a Portion of the Cloud Depiction in Figure 3-4 was Based.

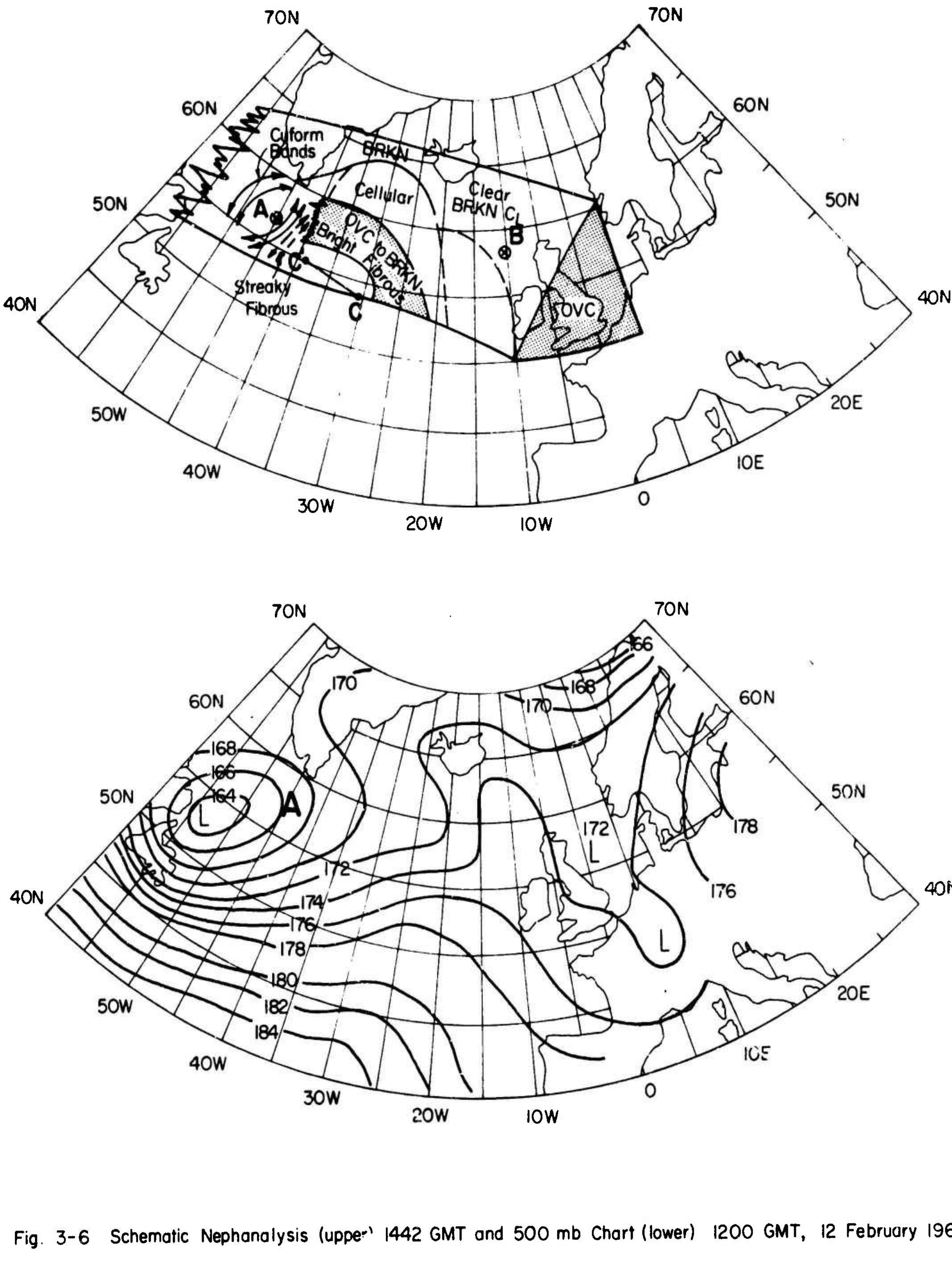


Fig. 3-6 Schematic Nephanalysis (upper) 1442 GMT and 500 mb Chart (lower) 1200 GMT, 12 February 1963.

A 500 mb ridge, located N-S through B and moving eastward at about 3° of latitude per day.

A short wave trough lying along CC'.

The 500 mb flow west of the ridge at B is generally southerly.

The general zonal flow south of CC' and the low at A is west-southwesterly.

The vertical motion fields associated with the short wave and closed 500 mb low west of the ridge at B are weak and weaken further with time.

The 500 mb and surface low are indicated by the character of the cumuliform bands near A, with the center of the low in the center of this banded pattern. The cyclonic system approaching Europe is indicated by the overcast cloud area at the eastern edge of the satellite data. The speed of this system is estimated from the movement of the western edge of the cloud system. The continuity of the clear area around B suggests the continued existence of the 500 mb ridge at B; this position is consistent with assuming the ridge moving eastward at the same speed as the cyclonic systems. The short wave trough is indicated by the crescent shaped cloud area north of CC'.

The southerly flow west of the ridge at B is indicated by the northward movement of the streaky cloud band and cellular cloud field, from south of CC' on the 11th to the northern edge of the satellite coverage southwest of Iceland on the 12th. The general southwesterly flow south of CC' and A is suggested by the fact that the short wave at CC' could not have moved into that area from due west because of the 500 mb low in that area.

The vertical motion field associated with the low at A has weakened during the past 24-hours as evidenced by the change in cloud character, near the center, from overcast fibrous to cumuliform bands. The vertical motion field associated with the short wave along CC' is weak, as indicated by the broken character of the cloud band. These are then weak systems, as vigorous systems are usually accompanied by strong vertical motion fields and heavily overcast cloud systems.

These two consecutive days suggest that easterly motion of systems north of 55N is occurring in the eastern Atlantic, but is being replaced by more southerly motion in the central Atlantic. This situation would suggest that the possibility of blocking is higher than normal, but there is no evidence that it definitely will occur in the immediate future. The available information would, however, be another input to the German meteorologists looking for the development of a blocking situation.

13 February 1963

The satellite data are presented in Figure 3-7. This nephanalysis was prepared from the TIROS V passes 3428 1410GMT and 3433 1730GMT.

Deduction of the synoptic situation:

A major oceanic cyclone developing near A, with the closed circulation just reaching 500 mb.

A cyclonic system located over western Europe, at B.

A 500 mb ridge located near 0^{o} Longitude (C).

The major oceanic cyclone is deduced from the type of cloud pattern near A. This is a typical hook pattern which is associated with a low developing from a short wave, with the closed circulation just reaching to 500 mb. The characteristic, east-west southern part of the hook (which in Figure 3-6 would run across A) is not observed because of the limits of the satellite coverage. The large cellular field observed southwest of A is frequently found to the rear of major oceanic storms.

The cyclonic system at B is deduced by the overcast cloud area at B and from continuity over the past few days. The 500 mb ridge is indicated at C from the clear area there and from continuity from the past two days. The easterly cyclonic system is moving eastward at about 8^{o} latitude per day as measured from the movement of the western edge of the cloud system. This movement would indicate general westerly flow at these longitudes.

The general flow in which a short wave (that from which the system at A is developing) is imbedded is west-southwest to southwest. This is suggested by the fact that cloudiness from this short wave was not evident in the satellit data south and west of A in Figure 3-6, for the 12th. This flow is consistent with that deduced for the same area for the 12th.

From the standpoint of forecasting a blocking situation, one should be aware that development of a major cyclonic system is taking place near A. A major cyclonic system is indicated by the rather large area being influenced by this system. This area stretches from the southwestern end of the cellular cloud area to the northeastern edge of the heavy overcast cloud, a distance of some 1000 nautical miles. That this is a major cyclonic system is also indicated by the strong upward vertical motion field associated with it, as evidenced in the satellite data by the large area of bright heavy overcast cloud. A major cyclonic development, deepening at 500 mb will produce a southerly flow of warm air to the east

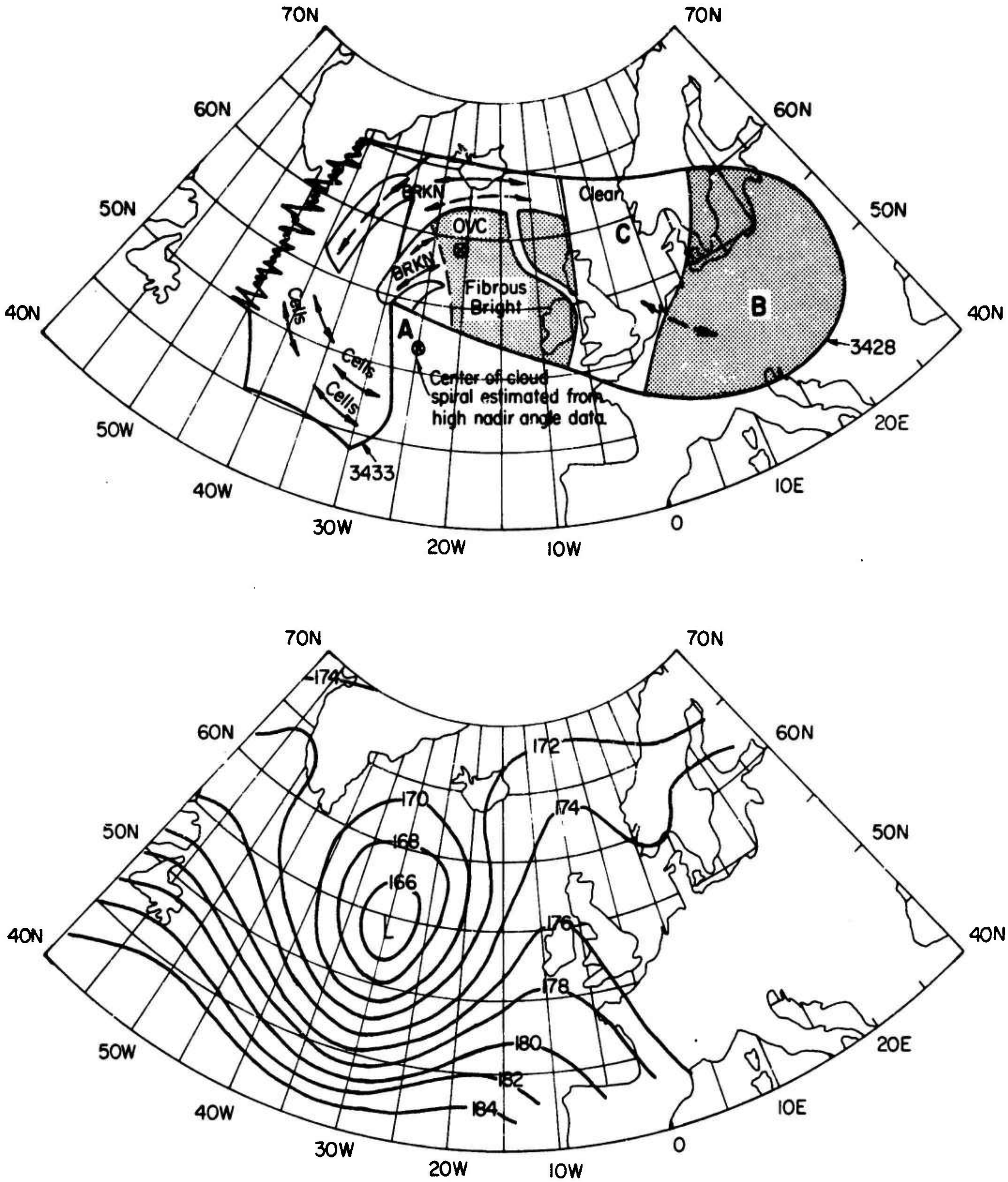


Fig. 3-7 Schematic Composite Nephanalysis (upper) for 1410 to 1730 GMT 500 mb Chart (lower) 1200 GMT, 13 February 1963.

of A. Such a cyclonic development with southerly flow of warm air is usually the precursor of the development of a blocking high, especially at these longitudes. Thus, the German meteorologist should be very conscious of the high probability of a block developing in the next twenty-four to forty-eight hours.

14 February 1963

Figure 3-8 presents the satellite data from TIROS V passes 3441, 1200 GMT and 3443,1523GMT. From continuity and the satellite data, the following synoptic situation can be deduced:

A quasi-stationary 500 mb ridge running N-S through F, with indications that the ridge is expanding its longitudinal size.

A closed 500 mb low located near A.

Southeasterly flow at 500 mb along the line D'D between the ridge at F and low at A.

A short wave trough in westerly to west-southwesterly mean flow, running N-S through EE'.

A small amplitude short wave at B, imbedded in the westerly flow around the bottom of the closed low at A.

A short wave disturbance (C) in the flow around the closed low to the northwest of the low center at A.

The 500 mb ridge is deduced from the clear area centered near F. The quasi-stationary character of this ridge is deduced from the fact that the N-S axis of this clear area has moved very little in twenty-four hours. The longitudinal expansion of the ridge is deduced from the change in the longitudinal size of the clear area, at 60N, from 5W to 15E on the 13th to 10W to 20E on the 14th.

The 500 mb low at A is deduced from the spiral banded structure of the cloud field at A, and the evolution of the cloud field over the past twenty-four hours, especially the appearance of this spiral banded structure in an area which twenty-four hours before contained bright, fibrous, overcast cloud.

The southeasterly flow at 500 mb along D'D is deduced from the northwest-southeast streaks in the broken clouds along D'D. The southeasterly flow is deduced from the combination of the ridge at F and the low at A. Also southeasterly flow is

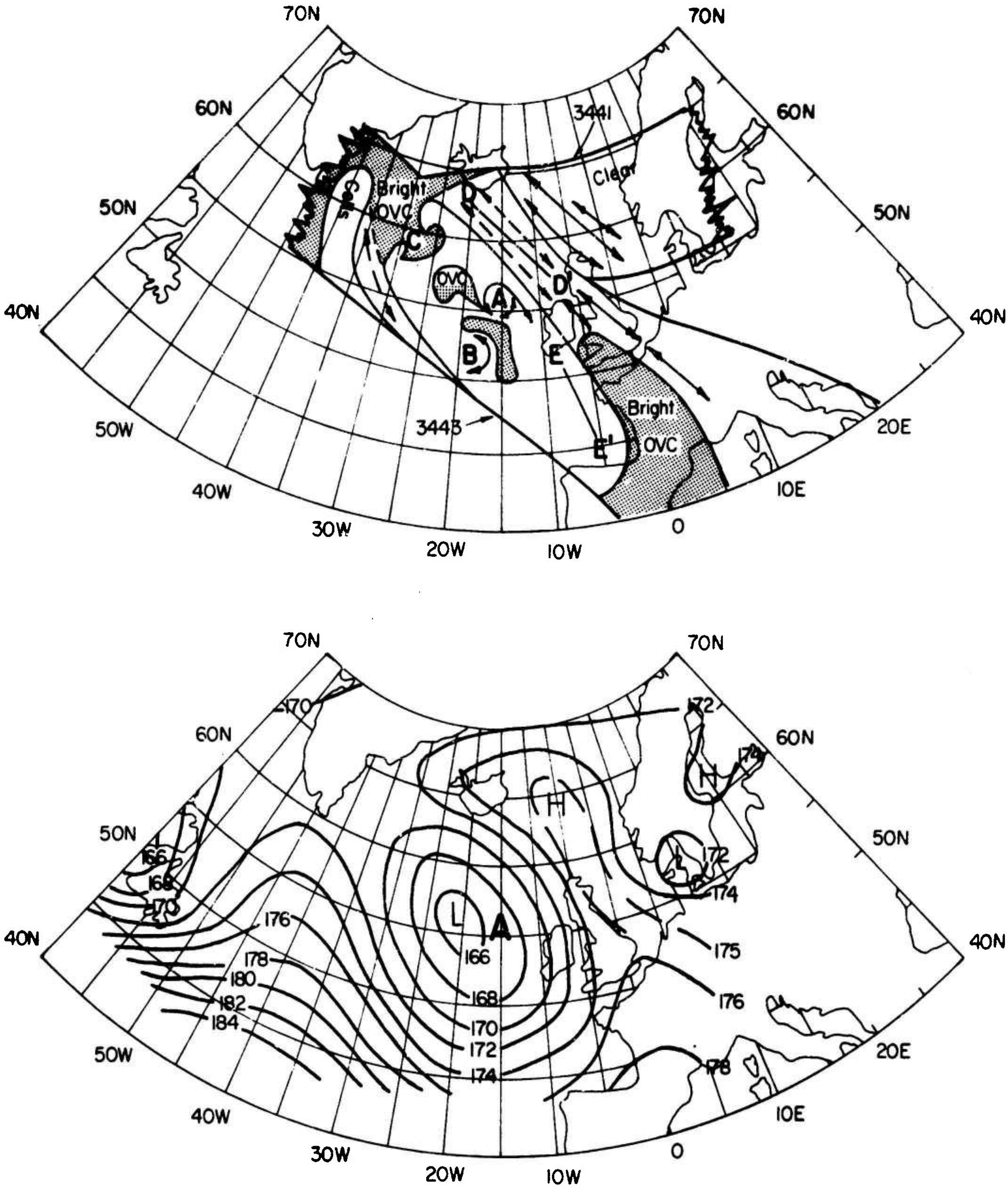


Fig. 3-8 Schematic Composite Nephanalysis (upper) for 1200–1523 GMT and 500 mb Chart (lower) for 1200 CMT, 14 February 1963.

suggested by the northwest movement of the heavy overcast cloud (at C on the 14th) from its position near A (of the 14th) on the 13th.

A short wave disturbance at C is deduced from the bright, heavy overcast cloud in this area. The evolution of a cyclonic system which has a hook cloud shape on one day is such that the bright overcast cloud, in the northeastern part of the hook, maintains its association with a short wave which is imbedded in the flow around the closed circulation which develops at 500 mb. The evolution of the cloud pattern from the 13th to the 14th, and the synoptic situation, strongly suggest that the cloud northeast of A on the 13th has moved northwestward to C on the 14th. This movement is consistant with the southeasterly flow along D'D.

The short wave trough along EE' is deduced from the bright overcast cloud area located east of EE'. The westerly to southwesterly flow is deduced from the fact that the western edge of this cloud area is oriented N-S.

The small amplitude short wave at B is deduced from the crescent shaped cloud mass near B.

The closed 500 mb low at A, the expanding 500 mb ridge at F, and the southeasterly flow along D'D would indicate to a German meteorologist that the development of a blocking situation was highly likely. Whether the blocking situation would completely cut off upper level systems from the Atlantic was not as important to the German attack plans as was the creation of light wind conditions near the surface. Once fog and low cloud were formed in the low levels, the light winds would maintain this condition. In the present case, the short wave along EE' was moving toward the battle area (50N, 6E) during the next twenty-four hours. The probable precipitation associated with this system would introduce moisture into the lower levels and the light low level wind conditions associated with the developing blocking situation would maintain these conditions for a prolonged period. Based on the satellite data for the 14th and the continuity from the preceding days, the German meteorologist would be able to predict a prolonged period of bad flying weather beginning on the 15th. Based on this information, the Germans would have planned to launch their counterattack on the morning of the 15th.

15 February 1963

Figure 3-9 presents the satellite data from the TIROS V passes 3455,1130 GMT, 3456,1311GMT, and 3459,1632GMT. From continuity and the satellite data, the following synoptic situation is deduced:

An expanding blocking ridge located at F.

A quasi-stationary 500 mb low at A.

A blocked situation in the eastern Atlantic.

The main band of westerlies at 500 mb in the eastern Atlantic is located near 45N at E.

The blocking ridge is deduced from the large clear area centered at F. The expansion of this ridge is deduced from the enlarging of the clear area. At 60N, the clear area has expanded to 25E (from 20E on the 14th); at 65N, the clear area has extended westward from 15W to 25W.

The 500 mb low is deduced from continuity; from the northward movement of the short wave disturbance at B, from 52N, 17W on the 14th, to 57N, 13W on the 15th; and from the westward movement of the shortwave disturbance at C, from 59N, 26W on the 14th, to 59N, 35W on the 15th.

The position of this 500 mb low at A is deduced from the spiral banded structure of the clouds in this area. This position is only about 1° from its position twenty-four hours earlier.

The blocked situation in the eastern Atlantic is deduced from the quasi-stationary character of the ridge at F and the low at A, from the development of the ridge at F, and from the motions of the systems at B and C over the past twenty-four hours.

The westerlies being located south of 45N in the eastern Atlantic, at E, is deduced from the bright overcast band, lying east-west, south of E.

From these data, the German meteorologist would be able to deduce that the blocking situation was well established in the eastern Atlantic. With no middle and/or high cloud entering the central Atlantic in the area of D and the westerlies south of E in the eastern Atlantic, the German meteorologist would be able to predict that the blocking situation would persist for as much as another three days. Thus, the Germans could expect bad flying conditions to continue for this period of time.

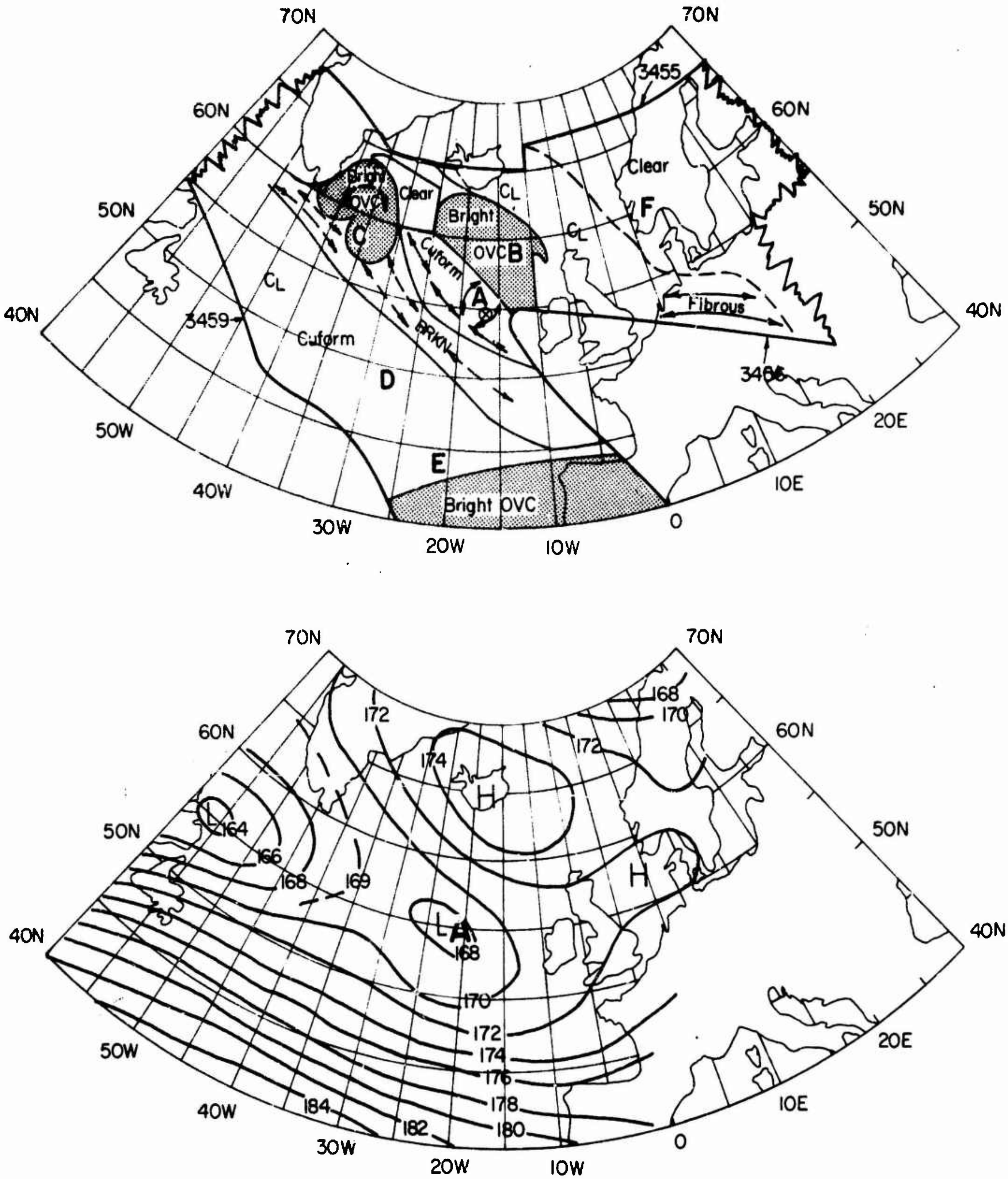


Fig. 3-9 Schematic Composite Nephanalysis (upper) for 1130-1623 GMT and 500 mb Chart (lower) for 1200 GMT, 15 February 1963.

16 February 1963

Figure 3-10 presents the satellite data from the TIROS passes 3469V 1055 GMT, 3470V 1238GMT, 3473V 1600GMT, and 2208VI 1305GMT. From continuity and the satellite data, the following synoptic situation is deduced:

A well-established ridge or blocking high located at B.

A quasi-stationary 500 mb low at A.

A 500 mb low at C.

A short wave trough, running parallel to DD' , along the cloud edge southwest of DD' .

The blocking ridge or high is deduced from the large clear area centered near B, and from the persistence of this clear area over the past forty-eight hours.

The 500 mb low is deduced from the spiral band pattern near A. This low is quasi-stationary, as shown by the very limited movement, from 54.5N, 17W on the 15th, to 53N, 17W on the 16th.

The 500 mb low at C is deduced from the spiral cloud pattern centered there. The apparent mis-analysis of the 500 mb map in this area is discussed below.

The short wave trough along DD' is deduced from the stage of development of the whole cloud system centered at C, and from the cloud spiral northeast of DD' .

The German meteorologist presented with these data would determine that the blocking situation was well established in the eastern Atlantic and would predict that fog and low cloud would persist for another forty-eight, and perhaps seventy-two, hours. The fact that the system at C appears as a 500 mb low indicates that a band of westerlies is not becoming established north of 50N at 40W. However, the progress of the short wave along DD' would have to be watched in the future as an indicator of how the pattern is evolving.

Example of the Modification of a 500 mb Analysis in a Sparse Data Area, Using Satellite Data

In Paragraph 4.3.4 it was stated that a modification of a 500 mb analysis in a sparse data area would be carried out to demonstrate the value of satellite data even in friendly data areas. The data for 1200 GMT on the 16th of February have

been chosen for this re-analysis. The area that will be re-analyzed is the western Atlantic south of Greenland. The satellite data used were the vortical cloud pattern located at C and along DD' in Figure 3-10. As mentioned above, the pattern of vortical cloud centered at C suggests a closed 500 mb low at C, and a short wave trough along DD'. The re-analysis based on the existence of these entities is shown in Figure 3-11a. The satellite data were taken in this area at 1600 GMT. To make the data contemporary, the cloud patterns were relocated to estimated positions for 1200 GMT. The relocation was based on both the stage of development of the satellite observed system and the conventional data.

Comparison of the original 500 mb analysis in Figure 3-10 and the revised one in Figure 3-11a shows the following points:

1. The satellite analysis produces a stronger gradient in the vicinity of the 105 knot wind from 220, near the short wave trough line, than the conventional analysis does.

2. The closed circulation and lower height analyzed near the center of the vortical cloud brings the contour field more in line with the 070° wind at 35 knots north of the center and the change in this wind from 090° at 50 knots 12 hours earlier.

3. Finally, the eastern location of the 500 mb closed center gives a smaller slope to the cyclonic system in that the closed center is located nearer the 1200 GMT position of the surface low shown in Figure 3-11a.

The magnitude and scale of the modification is shown in Figure 3-11b. The magnitude of the modification varies from a maximum of 400 feet lowering to 300 feet raising, of the contour heights. The scale of the change is such that the distance between the maximum change centers is only 360 nautical miles.

The persistence of the spiral cloud patterns at A in the satellite data, and continuity from the 500 mb chart for 15 February (Fig. 3-9), suggest that a weak closed center is still present near 53N 17W which is not revealed in the conventional data. This center has been indicated on the re-analysis in Figure 3-11a.

17 February 1963

Figure 3-12 presents the satellite date from TIROS passes 3484V 1206GMT, 3497V 1345GMT, and 2222VI 1033GMT

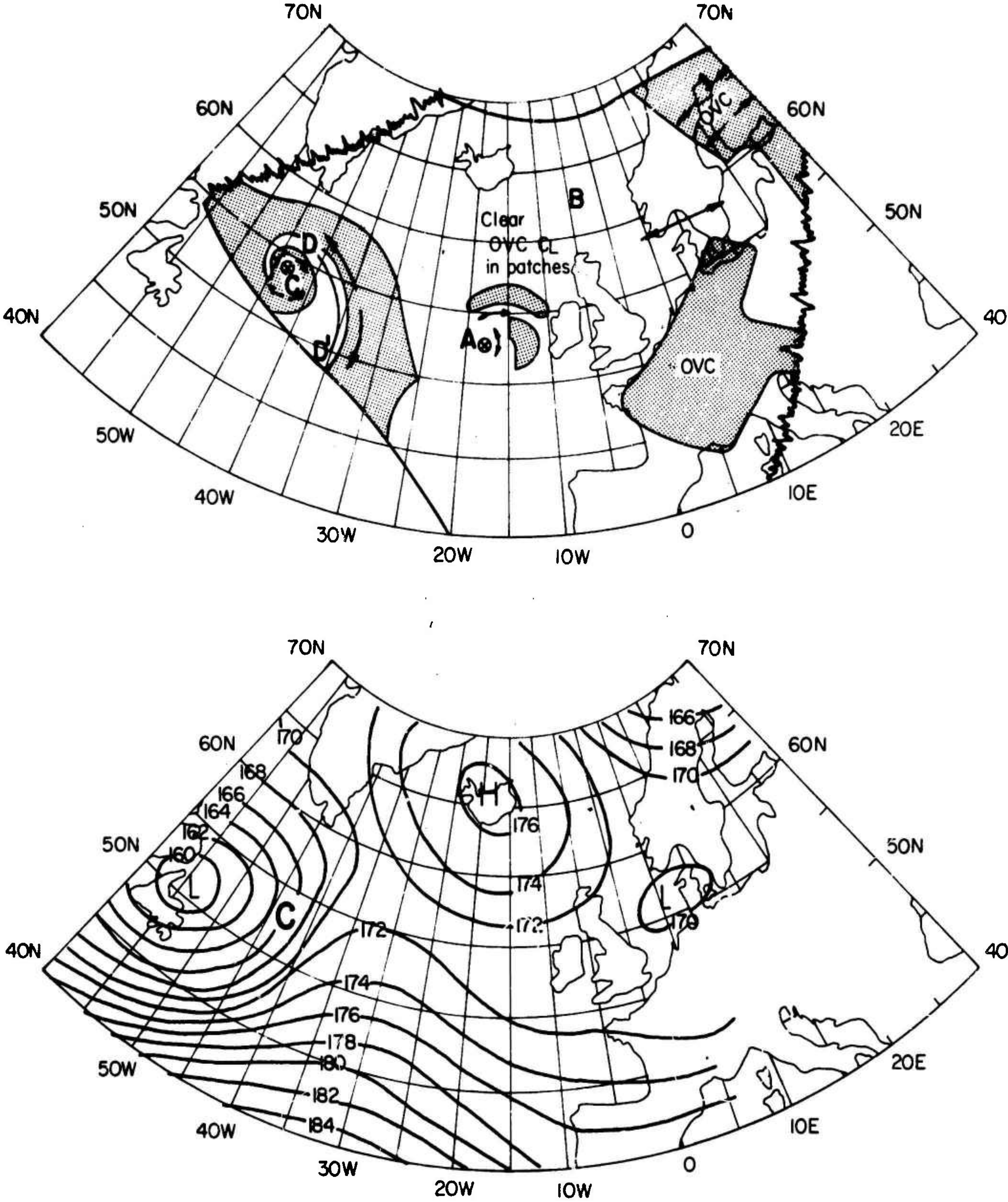


Fig. 3-10 Schematic Composite Nephanalysis (upper) for 1055-1600 GMT and 500 mb Chart (lower) for 1200 GMT, 16 February 1963.

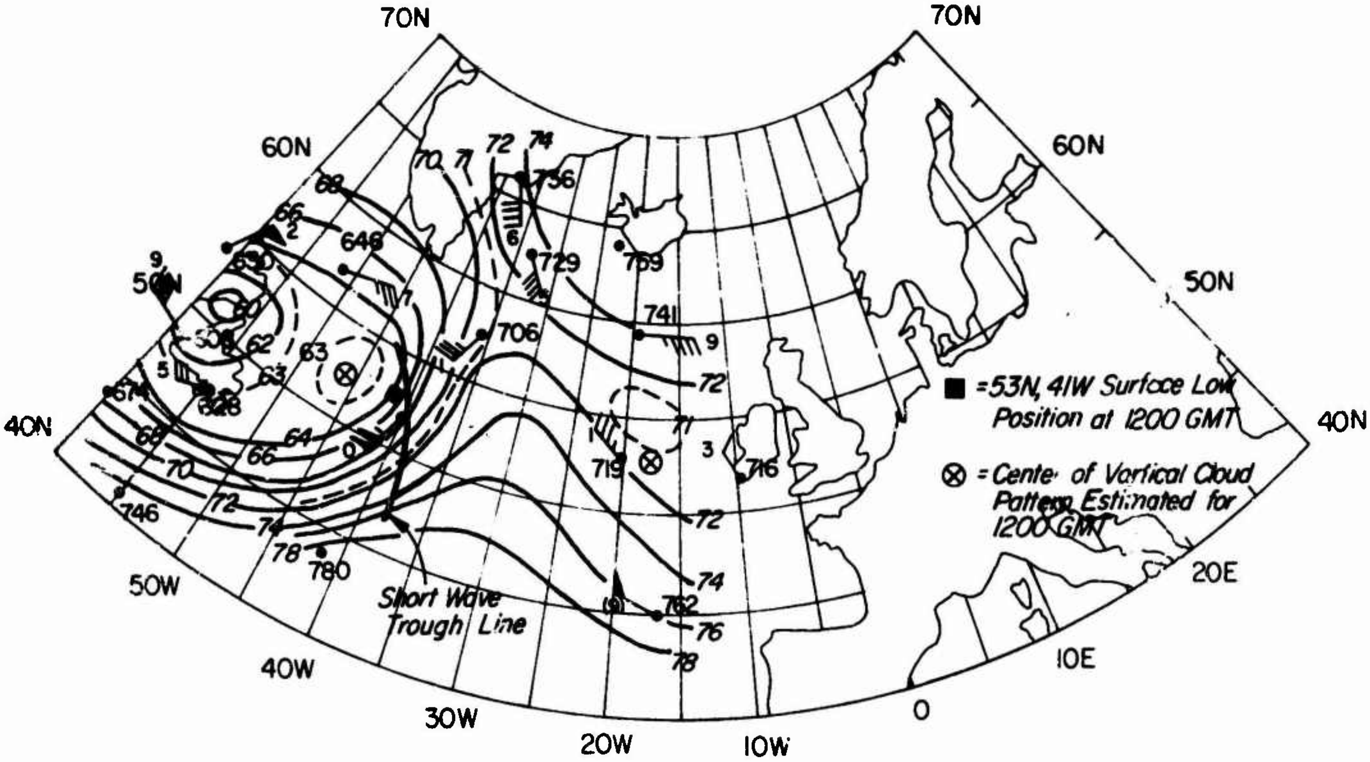


Fig. 3-11a Modified 500 mb Analysis for 1200 GMT, 16 February 1963.

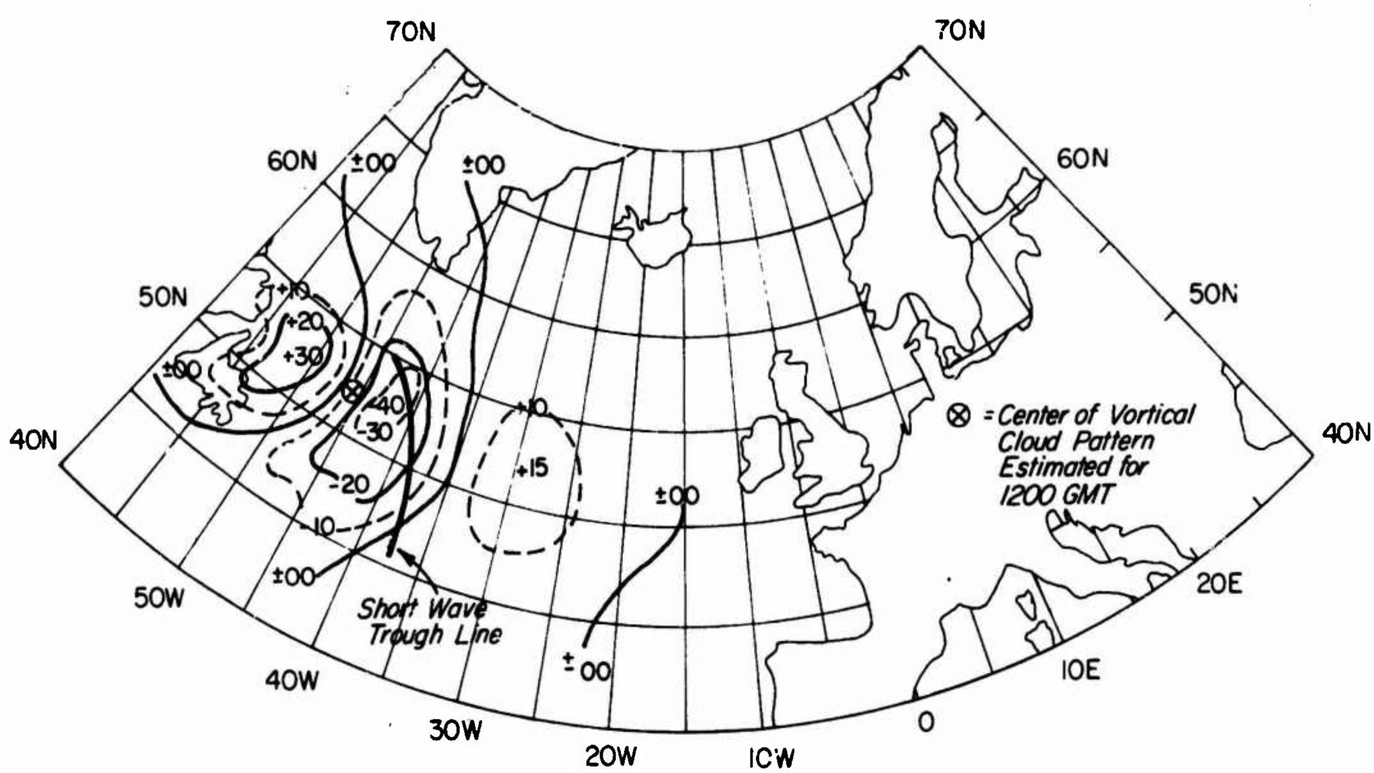


Fig. 3-11b 500 mb Contour Modifications Produced by Reanalysis Based on Satellite Data. Difference in Tens of Feet.

Deduction of the synoptic situation:

A well-established ridge or blocking high located at B.

Southeasterly and easterly winds at 500 mb along C' C.

A 500 mb low center in the vicinity of D.

The blocking ridge or high is again deduced from the large clear area centered near B and the persistence of this clear area over the past forty-eight hours.

The easterly winds at 500 mb near C are deduced from the west-east streaks in the cloud field there. The southeast winds near C' are deduced from continuity with the easterly winds at C and from the fact that the northeastern edge of the cloud band at C' has moved only 150 nautical miles toward the northeast in the past twenty-four hours.

The 500 mb low center at D is deduced from the wind flow along C' C and continuity with the position of the 500 mb low on the 16th.

The cloud pattern at A no longer shows any spiral band character and, hence, the 500 mb low at that location is deduced to have dissipated during the past twenty-four hours.

The German meteorologist would determine that the mid-tropospheric flow over the Atlantic was still blocked. In particular, the slow eastward progress of the cloud band at CC' indicates that the westerlies are still not established in the western Atlantic at latitude 55N. Thus, fog and low cloud should continue in the battle area for another forty-eight to seventy-two hours.

18 February 1963

Figure 3-13 presents the satellite data from the TIROS passes 3498V 1132 GMT and 2237VI 1252GMT.

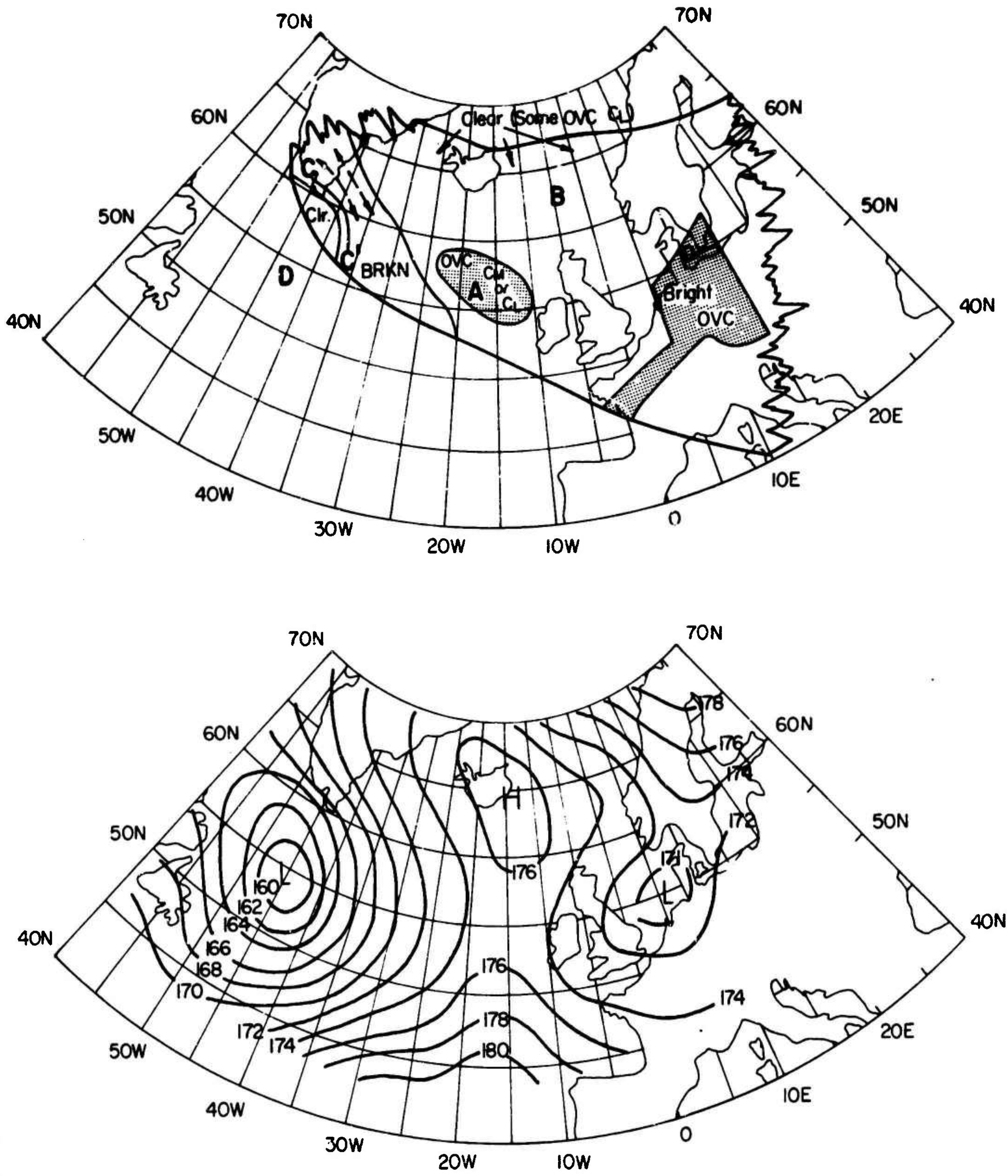
Deduction of the synoptic situation:

A quasi-stationary blocking ridge or high near B.

A slowly moving 500 mb low at A.

A 500 mb low at C.

Southeasterly winds along DD'.



ig. 3-12 Schematic Composite Nephanalysis (upper) for 1033-1345 GMT and 500 mb for 1200 GMT, 17 February 196

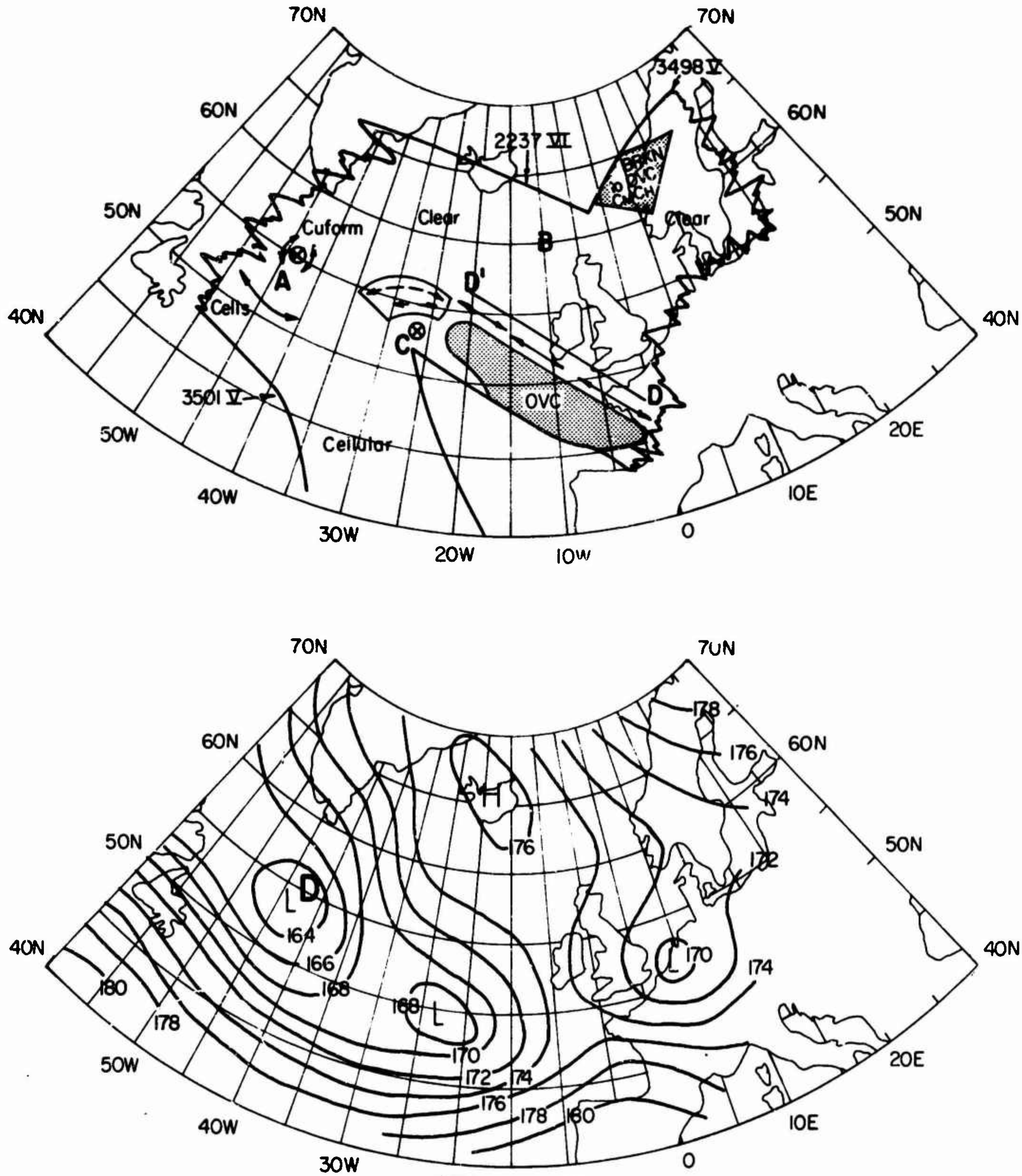


Fig. 3-13 Schematic Composite Nephanalysis (upper) for 1132-1635 GMT and 500 mb Chart for 1200 GMT, 18 February 1963.

The blocking ridge or high is deduced from the persistence of the clear area near B and the southeasterly winds along DD'.

The 500 mb low near A is deduced from the cloud pattern and from continuity with the synoptic pattern south of Greenland on the 16th.

The possible 500 mb low at C is suggested by the spiral cloud pattern there.

Southeasterly winds along DD' are deduced from the banded structure along DD', from the streakiness of the cloud southwest of DD', and also from the relative positions of the ridge at B and possible low at C. Finally, the cloud band southwest of DD' is the southern end of the band located east of DD' on the 16th. The eastern edge of this band has moved northeastward at 15 knots for the past forty-eight hours. This movement would suggest that the blocking pattern still exists in the eastern Atlantic and that well developed westerlies do not exist north of 45N.

The German meteorologist would determine that the eastern Atlantic was still blocked and that well developed westerlies still do not exist north of 45N. Thus, fog and low cloud should continue in the battle area for another forty-eight to seventy-two hours.

19 February 1963

Figure 3-14 presents the satellite data from the TIROS passes 3515V 1605 GMT and 2251VI 1514 GMT. These data are in the western and central Atlantic. A TIROS V pass, not shown, extending eastward from Norway and Sweden, showed clear skies over these areas.

Deduction of the synoptic situation:

The blocking ridge or high in the eastern Atlantic

An eastward moving surface and 500 mb low at A.

A weak short wave trough oriented N-S along BB'.

The blocking ridge is deduced from the clear area over Norway and Sweden.

The surface and 500 mb low at A is deduced from the cellular banding pattern around A.* This is the same system that was located at A, south of Greenland, on the 18th. That this is the same system is based on similar cellular pattern associated with both systems. This low has moved eastward at 25 knots for the past twenty-four hours.

*Examination shows the operational 500 mb analysis in Figure 3-14 could be reanalyzed to indicate a low at A.

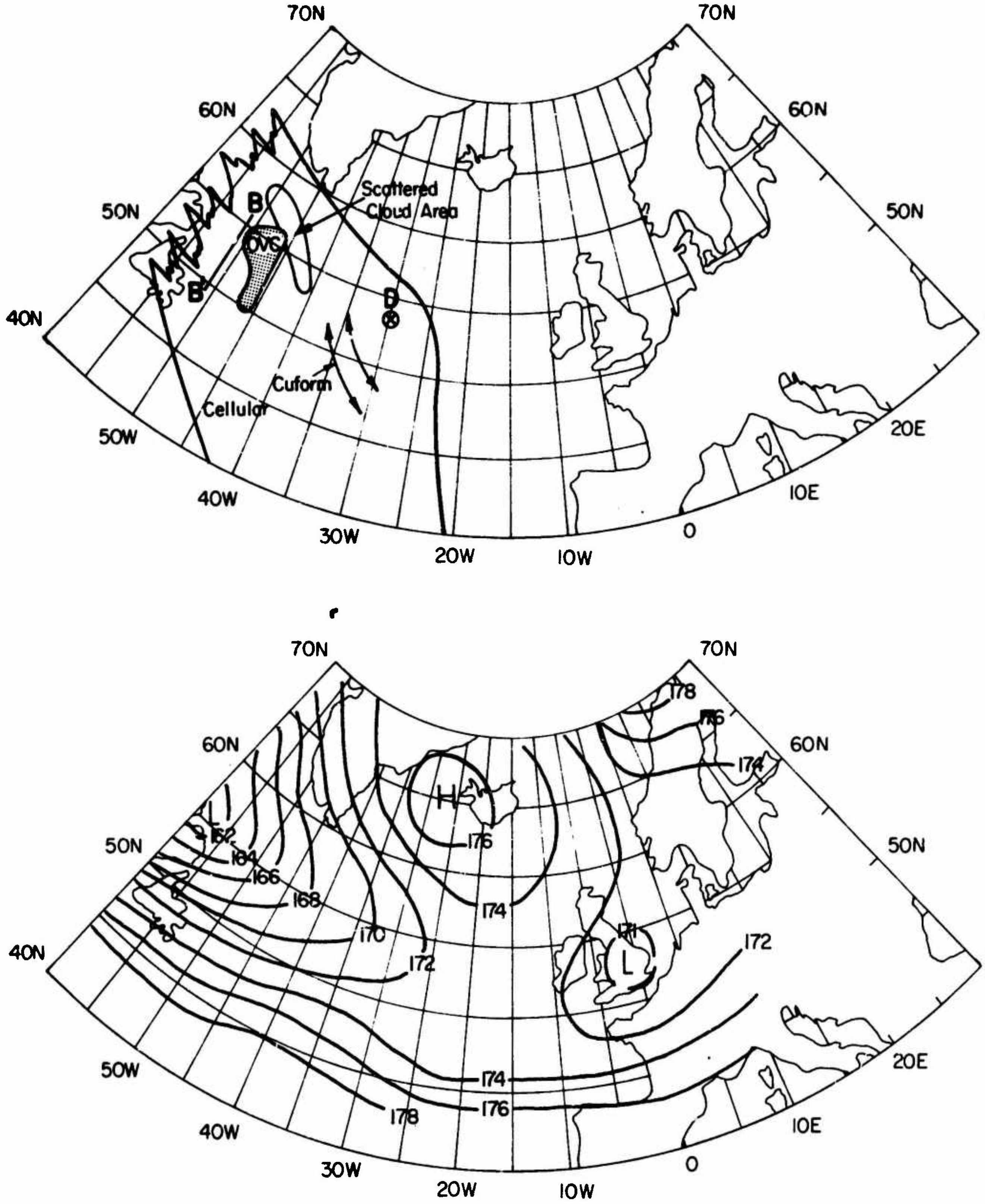


Fig. 3-14 Schematic Composite Nephanalysis (upper) for 1514-1605 GMT and 500 mb Chart (lower) for 1200 GMT, 19 February 1963.

The small amplitude short wave is deduced from the crescent pattern east of BB'. This system is shown to be weak by the small area of overcast middle and/or high cloudiness associated with it. This system is imbedded in a westerly flow, as can be deduced from the general N-S orientation of the crescent pattern.

A German meteorologist would determine that easterly motion of systems was being re-established across the Atlantic north of 50N with probable westerlies at 500 mb. With a speed of 25 knots, the short wave would reach the eastern Atlantic in about seventy-two hours. Thus, the blocking situation, with fog and low cloud, would likely continue for at most another seventy-two hours, and probably only for forty-eight hours. Thus, the Germans should be prepared for introduction of Allied air power into the battle by midday on the 21st.

20 February 1963

Figure 3-15 presents the satellite data from the TIROS pass 2265VI 1420GMT. TIROS V and VI were photographing the same area of the Atlantic at nearly the same time, therefore, only TIROS VI data were used. The coverage was such that no data were taken between 20W and 15E at 55N. However, data were taken in an area important for keeping track of events moving across the Atlantic.

A short wave trough is deduced to be imbedded in westerly flow along AA'.

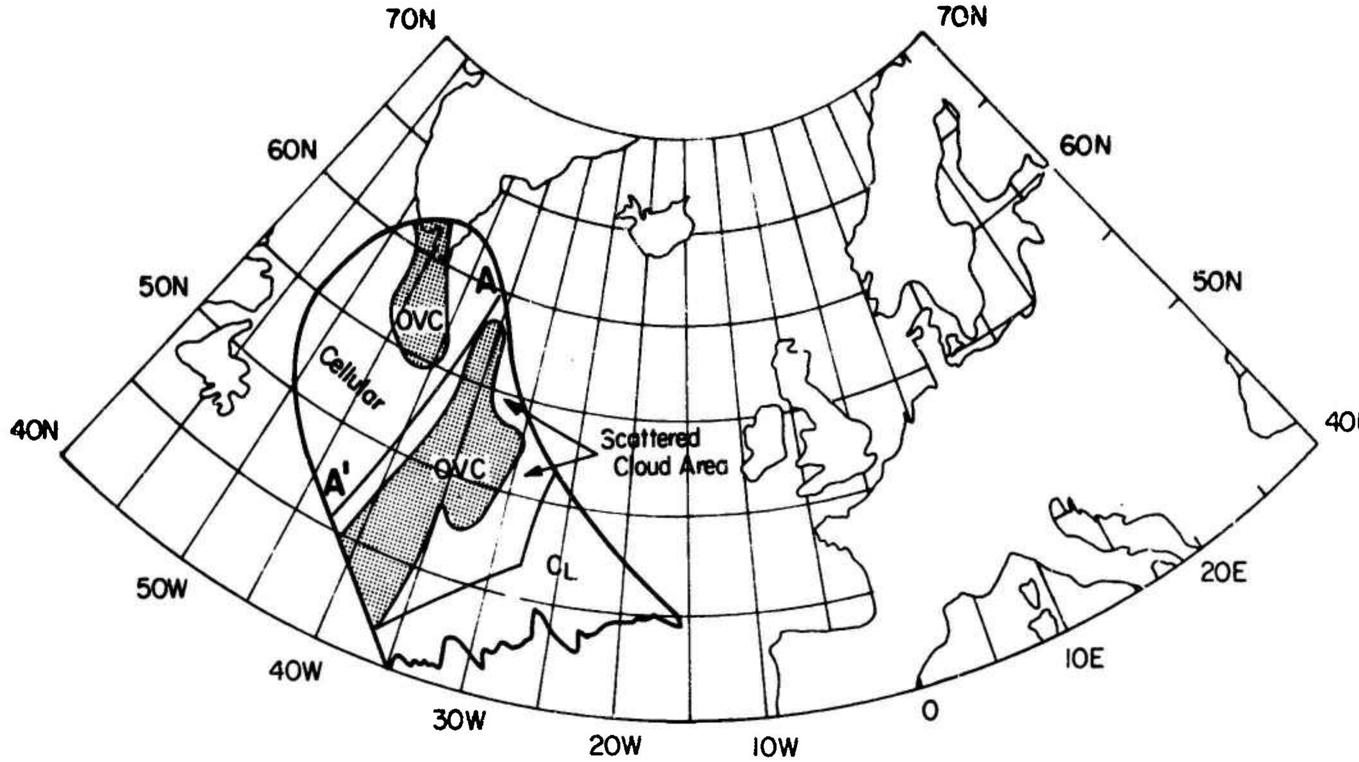
This short wave trough is deduced from the N-S band of overcast cloudiness east of AA'. This is the same short wave which was N-S through BB' on the 19th. That this is the same trough is deduced from:

1. Continuity in the N-S band part of the cloud pattern.

2. Continuity in the scattered cloud area to the east of the cloud band.

3. The speed of this system is 20 knots, which is consistent with the movement of the closed low during the previous day.

The German meteorologist would determine that westerlies at 500 mb were being re-established across the Atlantic at 55N, as evidenced by the eastward progress of the short wave trough. The speed of this system would suggest that the blocking situation over Belgium would last only for another forty-eight hours.



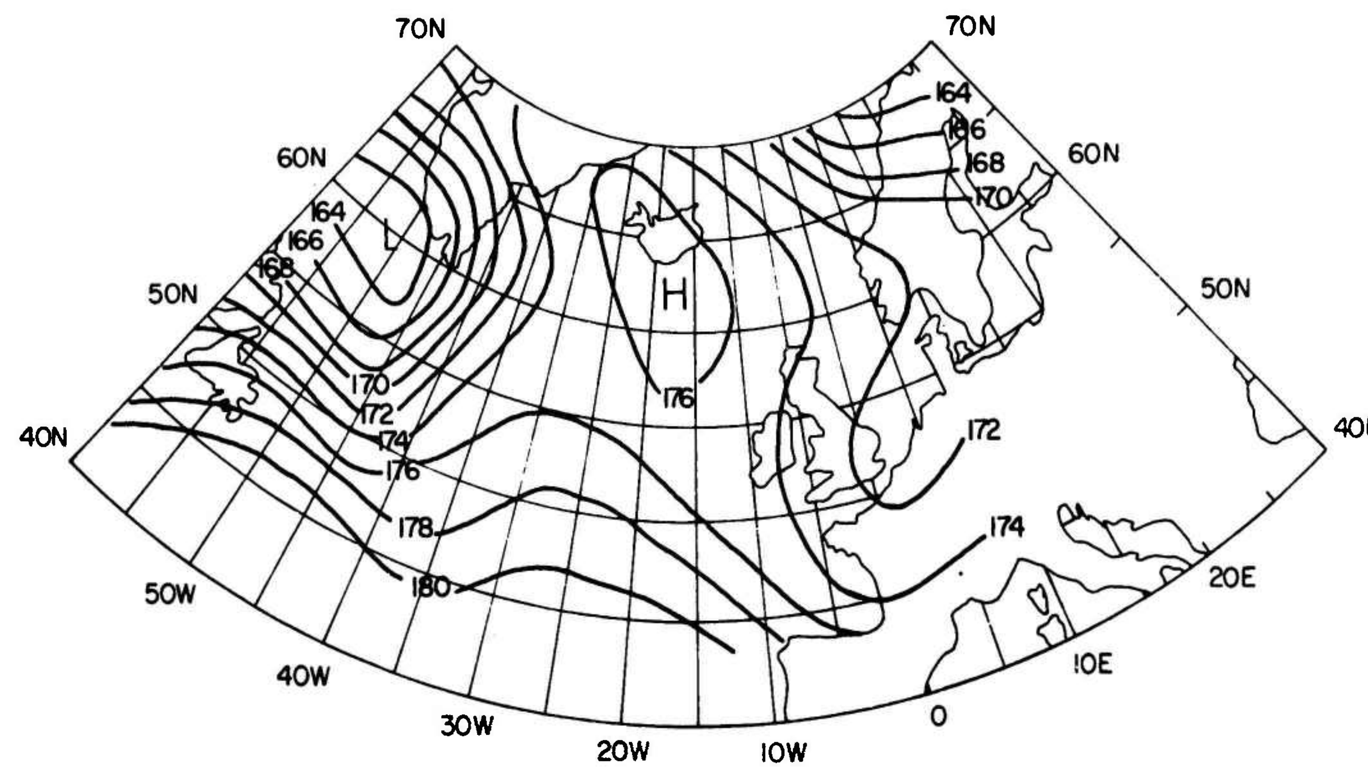


Fig. 3-15 Nephanalysis for 1420 GMT and 500 mb Chart for 1200 GMT, 20 February 1963.

21 February 1963

Figure 3-16 presents the satellite data from the TIROS pass 2280VI 1320 GMT. From these data we deduce a short wave trough along AA' and the eastern edge of the cloud system associated with the next system upstream (located along BB').

The short wave trough is deduced from the N-S cloud band east of AA'. This is the same trough as that along AA' on the 20th for the same reasons as those listed in the discussion of the 20th.

The German meteorologist would determine that the westerlies were being re-established further east with each passing day as the eastern short wave has progressed eastward over the past forty-eight hours. The westerlies appear to be well established across the middle Atlantic as further evidenced by the cloudiness from another more well defined short wave which is present in the middle Atlantic. There is little concrete evidence in the satellite data from which one could deduce exactly when the clearing in the battle area was going to take place. The area east of the cloud band along AA' was viewed at a very high nadir angle by the satellite. This area west of the battle area appears to contain only broken to scattered cloudiness. With this information and the fact that the systems were moving across the Atlantic at 20 knots, the German meteorologist should predict clearing in the battle area within forty-eight hours at the latest and possibly as soon as twenty-four hours.

22 February 1963

Figure 3-17 presents the satellite data from the TIROS pass 3558V 1240GMT. From these data we see that all of western Europe between 10E and line AA', is clear. Line AA' marks the eastern edge of the cloud system associated with the short wave trough in the middle Atlantic.

From these data, the German meteorologist could see that the clear area extended westward to 17W. This eastern edge is moving eastward at 7° of latitude per day, which means that the clear skies would last for at least another forty-eight hours before the onset of the next storm system. Thus, the Germans would be subject to attack from the Allied air power for another forty-eight hours.

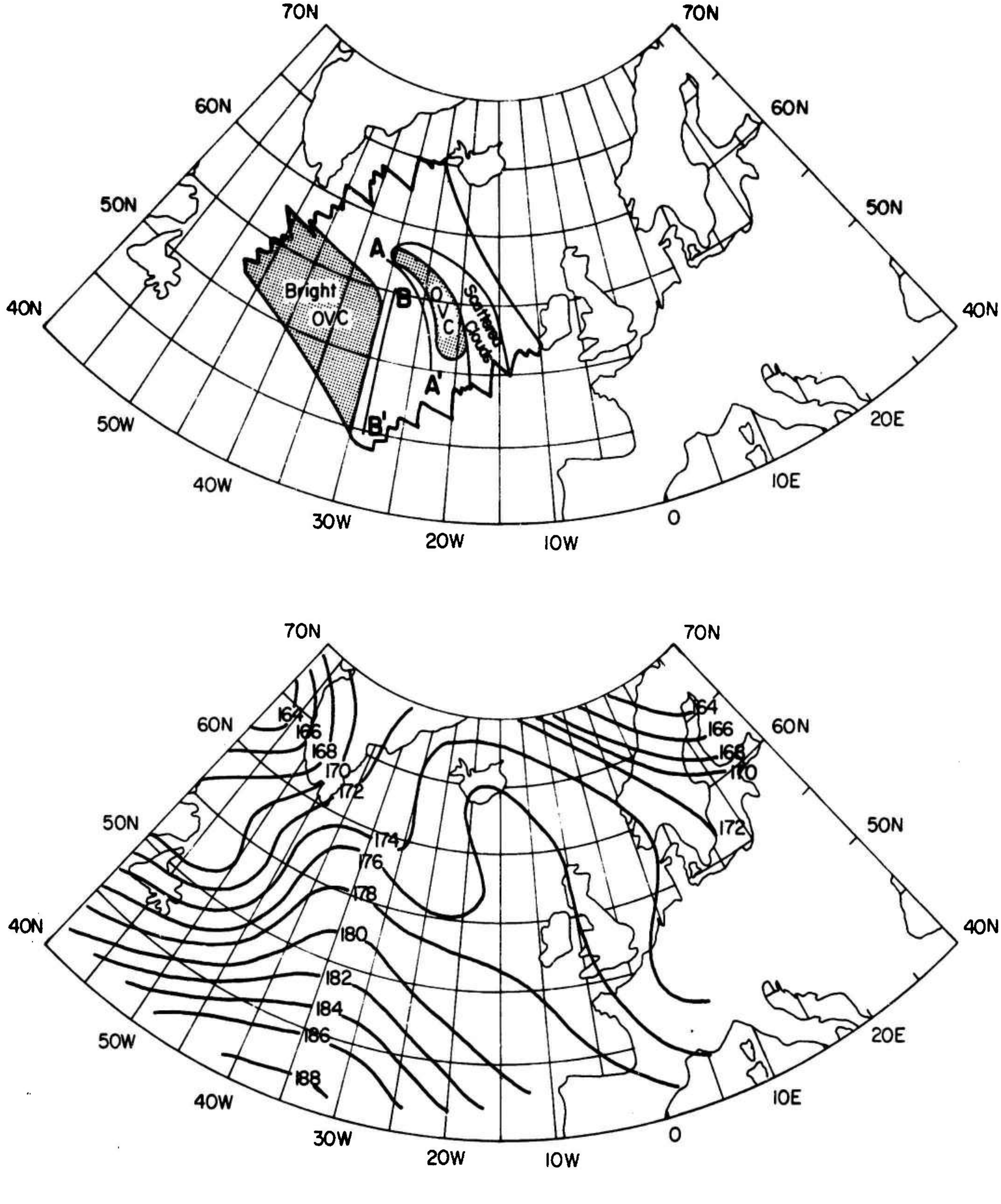


Fig. 3-16 Nephanalysis for 1320 GMT and 500 mb Chart for 1200 GMT, 21 February 1963.

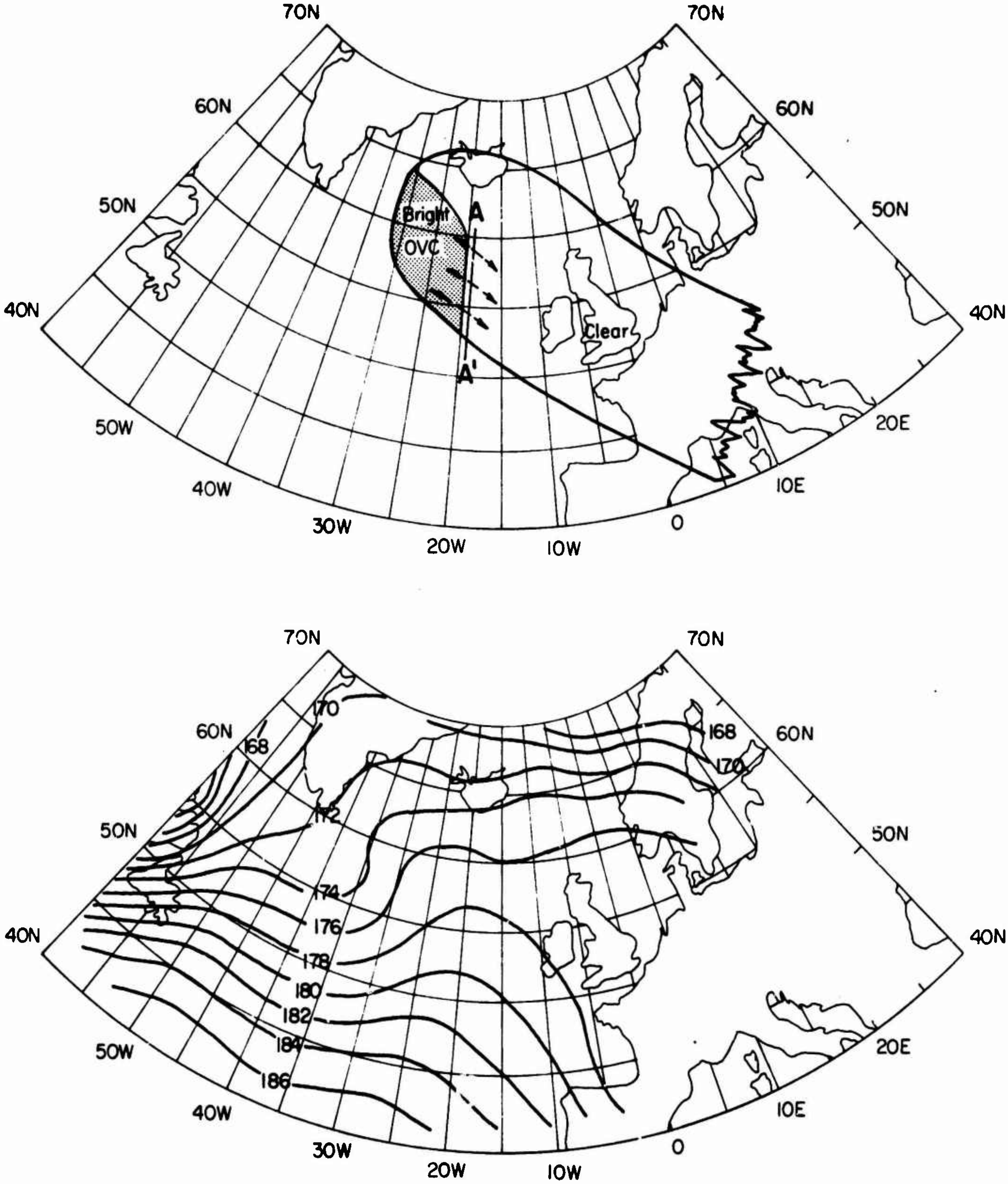


Fig. 3-17 Nephanalysis for 1240 GMT and 500 mb Chart for 1200 GMT, 22 February 1963.

3.3.8 Recapitulation

In this section it has been shown that the satellite data would help a meteorologist to analyze and predict the synoptic events in a silent data area. The presentation has been from the viewpoint of a German meteorologist during a period of weather similar to that which occurred during the Battle of the Bulge. From the satellite data, the German or Allied meteorologists would have been able to follow the development of a blocking situation, the maintenance of this blocking situation over a period of days, and the eventual breakdown of the blocking pattern. These deductions were made from the satellite data alone, based on good synoptic judgment and experience using the satellite data. From the Allied viewpoint, the addition and integration of whatever conventional data was available from radiosondes in England or ship reports from the Atlantic, would have allowed a far better synoptic analysis of the silent data area and, hence, to fewer forecast problems.

3.4 Phase 2 - Korean Case Study

3.4.1 Introduction

During the Korean Conflict, the Allied Army was faced with meteorological problems that were often quite different from those (except in the immediate area of Japan) of World War II. Weather situations peculiar to Korea (the eastern coastal area of a large continent) were not encountered in the European Theatre nor in the operations carried out in the more southern Pacific regions. In Korea, the Army found itself in a position of having a large silent data area to the west, the direction from which a great many of the weather systems affecting Korea arrive. The meteorological satellite, therefore, would probably have been of even greater value to the Army in Korea than in Europe although the North Atlantic proved to be a formidable, relatively silent data area in World War II.

Furthermore, in Korea, close support air operations were utilized to a higher degree than in World War II, making weather forecasting even more critical to the success of field operations. Therefore, a study of the uses of the satellite in K ean weather situations is highly desirable, especially since many present Army personnel were intimately associated with that conflict and had a personal involvement in the problems encountered.

3.4.2 Korean Weather

Korea, situated between 35° and 40°N on the east coast of Asia, has a climate controlled largely by the Asiatic monsoonal circulation (Reference 17). The majority of the precipitation occurs from May to September, when the region is under the influence of warm air masses. In winter, the weather is cold and dry, with few cyclones and, hence, there is less precipitation than along the east coast of North America. There is an occasional typhoon in late summer or fall.

A critical period, in terms of forecasting problems, is the period of transition from the summer to the winter regime. Usually in September the polar front begins to move southward and brings the summer heat to an end. From September to November, the polar front is located near or south of Korea and the weather fluctuates greatly as cyclonic storm systems pass through the region. In 1950, by the end of September, the average position of the front had become established southeast of Japan and a series of warm cyclonic systems, each followed by cold northerly winds, moved across the peninsula (Reference 25). Deep wave-cyclones produced cloudiness (that hindered air operations) and precipitation and, occasionally, valley fog in the calm air following the cold frontal passage. On other occasions, especially in November, bitter northerly winds followed the frontal passages.

The weather during this transition period also appears to fluctuate widely from year to year. In 1951, for example, when a series of high pressure cells dominated the region early October was extremely dry. This resulted in equipment difficulties due to dust. The heavier rain and snow of November finally ended the dust problem (Reference 25).

3.4.3 Selection of Period for Study

Naturally the Army was faced with certain prediction problems in all seasons during the Korean Conflict. Late winter thaws, produced by frontal waves that developed to the west over China, were among the most difficult to predict. The satellite would have been an invaluable aid to the Army in most of these situations. For this study, however, the autumn transition period was selected as TIROS VIII provided excellent coverage of the region during October 1964. During the autumn of 1964, many weather situations occurred that are analogous to situations that occurred during 1950 and 1951. By examining satellite data over a period of a month, it can be shown that the satellite can be utilized by the Army as a prediction tool for a series of weather systems.

3.4.3.1 Korean Weather Situations During Autumn 1950 and 1951

During the late summer and autumn of both years of the Korean Conflict, there were various situations that resulted in problems for Army operations (Reference 25). As early in the season as 21-22 August 1950, a cold front moved southward across the Korean peninsula and disrupted air operations. On 16 September of the same year, a cold front moved southward behind a cyclonic wave bringing the summer heat to an abrupt end. On 27 September another wave moved out of China bringing considerable cloudiness with low ceilings.

In one situation in October 1950, the rapid approach of fog, clouds, and precipitation severely limited artillery and air support. During the period 19-21 October, three cold fronts in succession moved southward across Korea. On the 20th, the third frontal cloud band became stationary across central Korea, although weather maps showed the front continuing to move toward the south. Cyclogenesis occurred over Korea, producing weather that caused the critical delay of a paratroop drop. Finally, in early November 1950, an unexpected secondary cold front brought heavy snow showers, resulting in severe trafficability problems.

These examples demonstrate that during the autumn, significant weather problems can be caused by cyclonic waves originating over China and passing either through or to the north of Korea. Due to the silent data area to the north and west, these systems and the cold fronts associated with them, were largely undetected until they actually arrived over Korea. The meteorological satellite can detect similar waves and frontal bands (Figs. 3-26 and 3-28), and could have provided vital information of their existence to the Army in Korea.

3.4.4 Case Studies-Korea

Three separate case analogs were selected for study from October 1964. Each case is a period of from two to four days, during which a particular weather system influenced the region. For each case there was daily satellite coverage; the pictures are presented under the case discussions. 500 mb and surface data nearest the times of the satellite observations are also presented with data plotted for selected stations. An additional case (not prepared under this contract) for the analog period of Autumn 1964, which demonstrates the use of DRIR (Direct Readout Infrared) for similar conditions appears in Reference 34. This report was

prepared by ARACON using Nimbus I HRIR data which has many similarities to the DRIR data expected to be available for field use.

The three cases which follow clearly demonstrate the capability of the satellite to provide data for (1) the interpretation and movements of well-developed systems approaching Korea from the north or west (Figs. 3-18 to 3-25), (2) the detection of a probable frontal wave development over northern Korea (Figs 3-26 to 3-29), and (3) the detection and tracking of significant systems which develop rapidly and unexpectedly nearly over the Korean Peninsula (Figs. 3-30 to 3-32).

3.4.4.1 General Discussion of Case I, 2-5 October 1964

In the first case, during the period 2-5 October, a bright cloud band is observed in the satellite data to move slowly across Korea from the northwest. Conventional data show that a blocking situation at 500 mb existed north of Korea during this period. At the surface, a deepening wave passed to the north of Korea, with a cold front passing across the peninsula.

In this case, as in the others, conventional data for the region are not as complete as might be desired. The only information to corroborate the satellite data on cloud cover and precipitation is from the surface charts. Because of this, it is difficult, for example, to provide corroborative data for the probability of precipitation determined from the satellite pictures, as in Section 5. However, the data are sufficient to demonstrate the values of the satellite data if it had been available for use by the Army in Korea.

2 October 1964

On the first day of this case, at about 0600 GMT, a satellite picture (Fig. 3-18) shows the Korean Peninsula to be cloud covered, but with some broken areas over the northern part. The same picture shows a brighter and more solid appearing cloud area to the northwest of Korea. Although the pattern of this cloud area cannot be determined exactly, it does appear to have a slight cyclonic circulation and it broadens toward the northeast. This pattern is similar to the patterns that have been shown by Rogers (Reference 2) to be associated with mid-tropospheric short wave troughs.

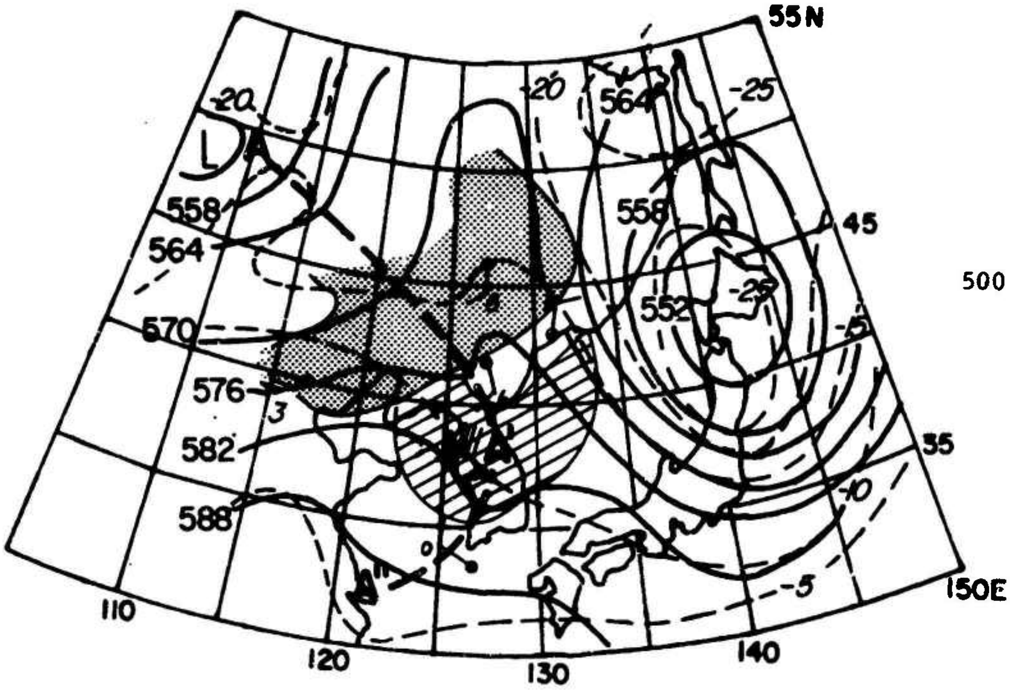
A surface wave is associated with the 500 mb system at 0600 GMT (Fig. 3-19). At this time mostly cloudy skies are reported over Korea with no precipitation occurring. A blocking situation at 500 mb appears to be developing, with a strong vortex to the east of Korea. The cloud area seen in the upper part of Figure 3-18 is undoubtedly associated with the short wave (line A-A' in Fig. 3-19) while the cloud cover over Korea may be a result of the minor short wave (line A'-A'' in Fig. 3-19).

3 October 1964

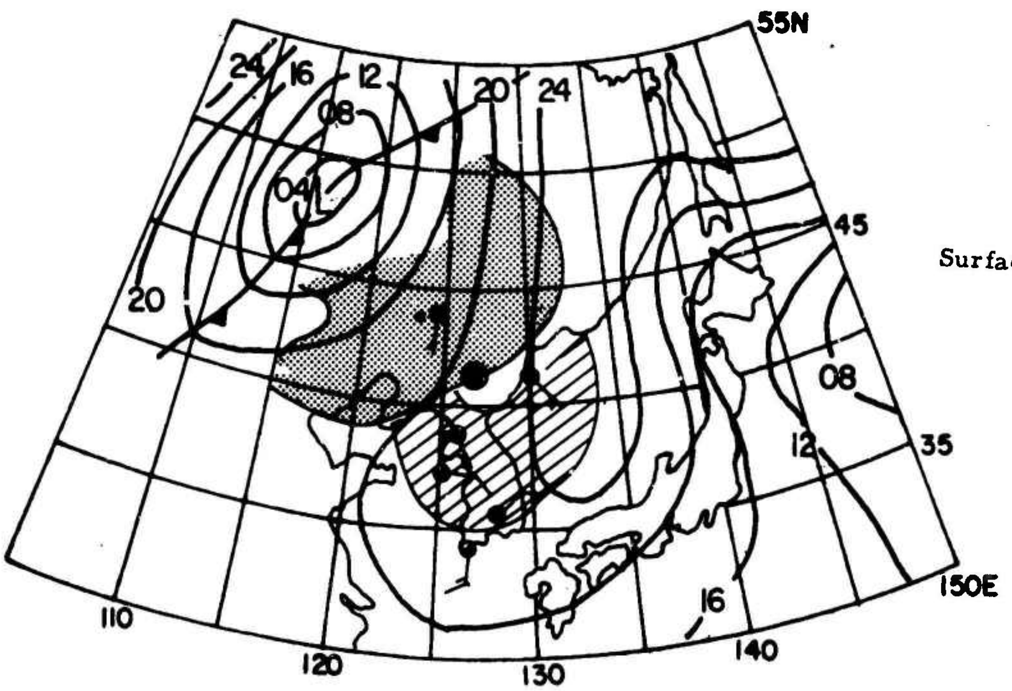
On the second day, at 0528 GMT (Fig. 3-20), the cloud band has definitely acquired the pattern that is generally associated with a short wave. The band stretching toward the south would be expected to be associated with a cold front at the surface. Korea is still cloud covered to a large extent, but there is an obvious difference in the appearance of the clouds over Korea and the major cloud band to the northwest. Most of the cloud cover over Korea is not bright and does not appear to be solid nor well organized. On the other hand, the cloud band is bright (some very bright areas near 40N 130E indicate areas of enhanced vertical motion) and more solid appearing. It was found in Section 5 of this report that a band of this type would have a higher probability of producing precipitation than would the clouds to the south.

At 500 mb (0000 GMT) the quasi-blocking configuration is now well developed and the entire "block" has moved slightly eastward (Fig. 3-21). The center of the trough located to the northwest of Korea has moved southwestward, under the influence of the short wave, and is now near the position of the cloud band seen in Figure 3-20. The outline of the band shown in the picture has been transposed to both maps of Figure 3-21 for ready comparison. At the surface (Fig. 3-21), the wave has deepened with a cold front indicated to be just west of Korea (0600 GMT). Cloud cover is reported over most of Korea, with some rain occurring to the west along the front. The satellite clearly shows the major cloudiness to be ahead of the cold front, a fact which is difficult to deduce from even the best of surface observations.

On this day, if there were no conventional data from North Korea or China, the major cloud band and cold front might not have been detected without satellite data. In time of war there would be little or no conventional data from the area where the most significant weather events are taking place. But as can be seen from Figures 3-20 and 3-21, the satellite would have allowed users to both recognize the existence of a significant weather producing system, and to make judgments about changes in cloud cover and temperature which might occur during the next several hours.



500 MB



Surface

Fig. 3-19 500 mb Chart for 0000 GMT, 2 October 1964 and Surface Chart for 0600 GMT, 2 October 1964. Dotted Shading Indicates Broken-to-Covered Clouds, Slashed Shading Indicates Scattered-to-Broken Cloud Cover.

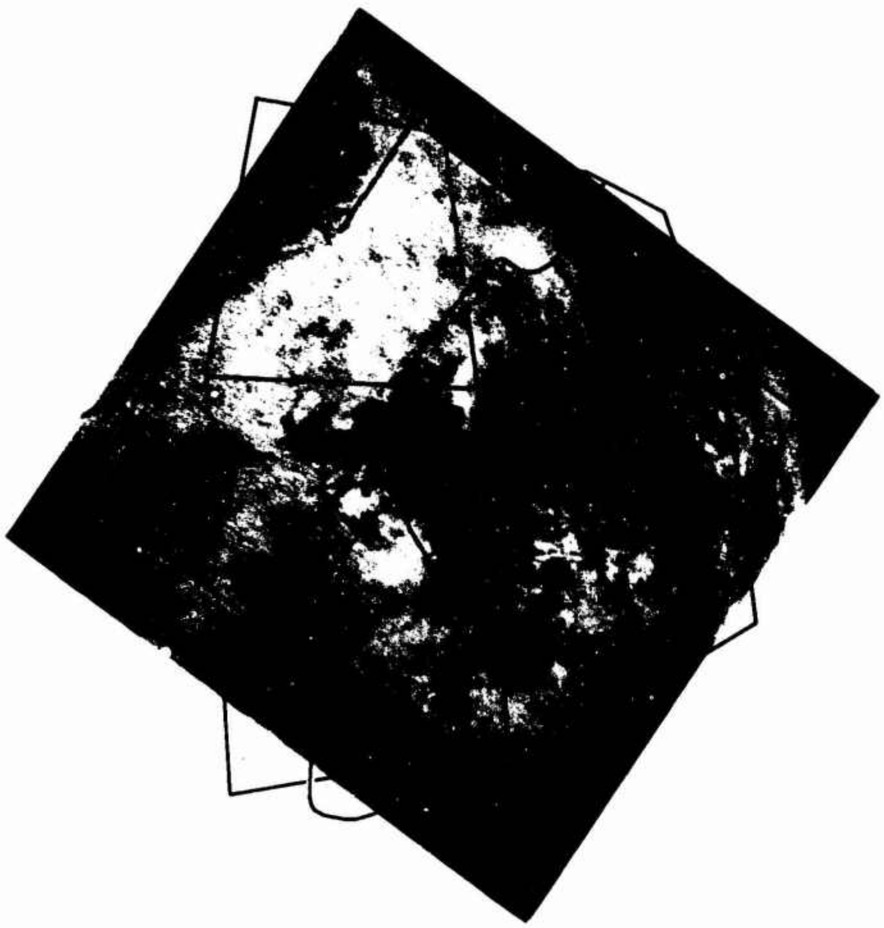
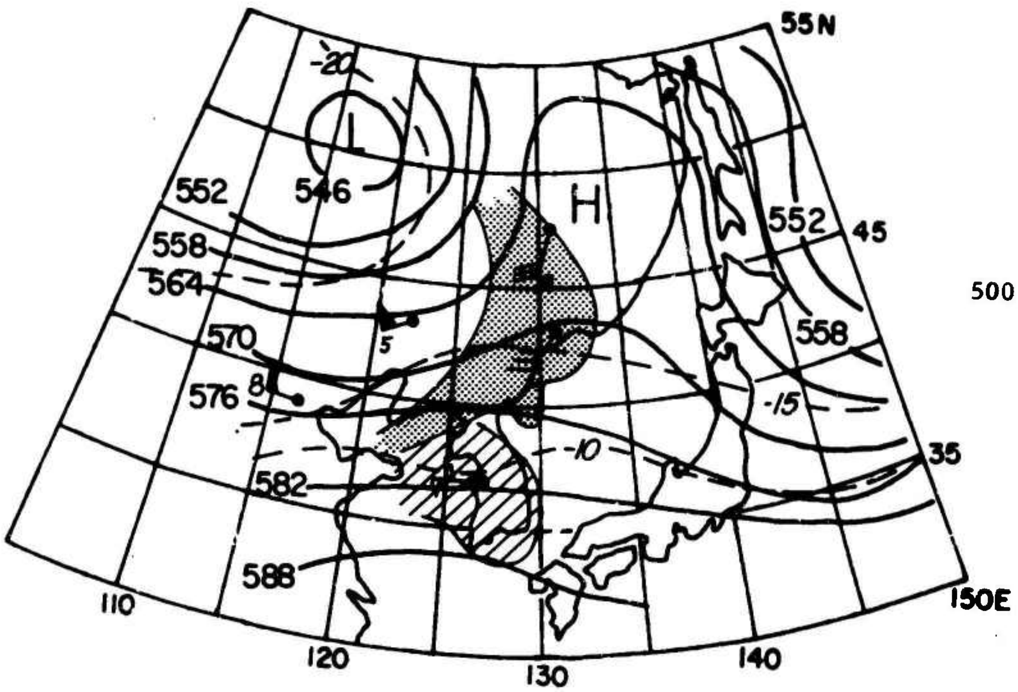
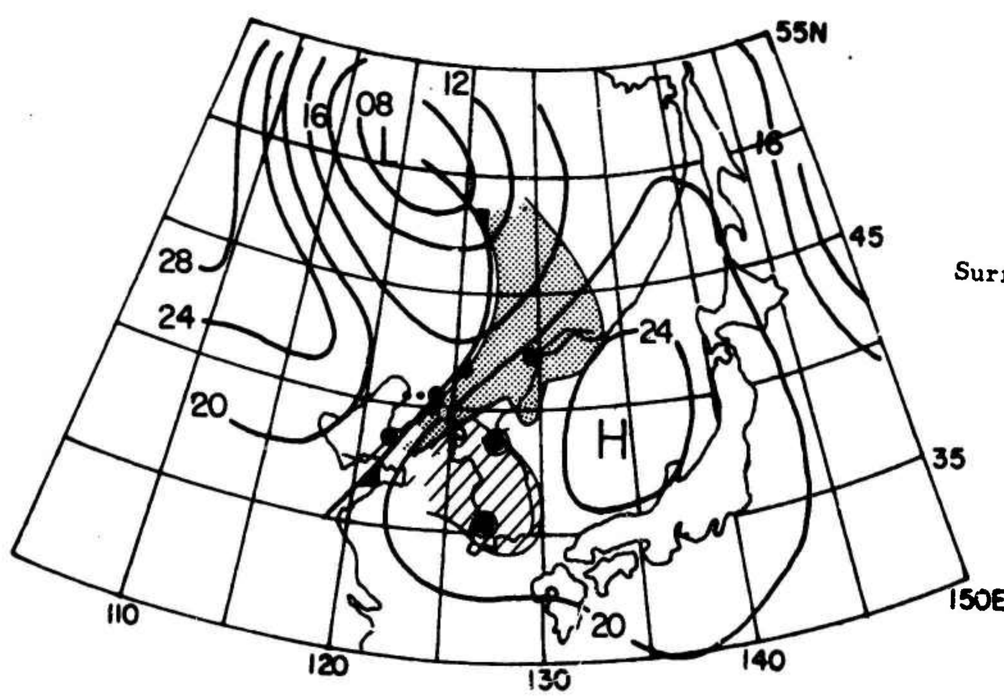


Fig. 3-20 TIROS VIII Photograph, Orbit 4159/4158, 0532 GMT, 3 October 1964.



500 MB



Surface

Fig. 3-21 500 mb Chart for 0000 GMT, 3 October 1964 and Surface Chart for 0600 GMT, 3 October 1964.

4 October 1964

On this day, there is satellite coverage of only the northern part of Korea, but the frontal band is seen in Figure 3-22 (0620 GMT) to extend through this part and probably a part of South Korea as well. The frontal band has a well-defined northwestern edge with a clear area to the north and a large cloud covered area further to the north. Patterns such as this, over land, have often been found to be associated with a mid-troposphere short wave trough located on the eastern side of a closed circulation (Reference 25). In Figure 3-22, the short wave producing the principal vertical motion would likely be centered at about 50N, 135E; the cloud area to the north of the clear section most likely consists of middle-level clouds advected into and around the closed circulation.

The cloud pattern seen by the satellite fits well with the 500 mb situation (Fig. 3-23). The short wave is apparently centered near 53N, 135W (line AA' in Fig. 3-23) with the closed circulation just to the west. Some vertical motion is likely taking place along the frontal or baroclinic zone, south then southwestward from where the short wave is centered.

The center of the surface system is now north of Korea (Fig. 3-23) and is no longer deepening. Although no fronts are drawn on the 0600 GMT chart, the winds and especially dew points indicate a frontal zone lying just to the north and west of Korea. There is considerable rain and fog in this area, with broken cloud cover over South Korea.

The satellite has shown the extent of the cloud band over the northern parts of Korea where it might otherwise be undetected, except perhaps by costly aerial reconnaissance. The slow movement of the band and the clear area north of it are clearly depicted by the satellite.

5 October 1964

The final satellite picture of this series at 0528 GMT (Fig. 3-24) shows a cloud band across all except northern Korea, where clear skies are observed. The northern coast of the Yellow Sea can be seen in this picture. It is apparent that the frontal band has moved southward, maintaining the same form, with a well defined edge and clear area to the north. The band still has some brighter areas in it, indicating thicker clouds and probable areas of greater vertical motions.

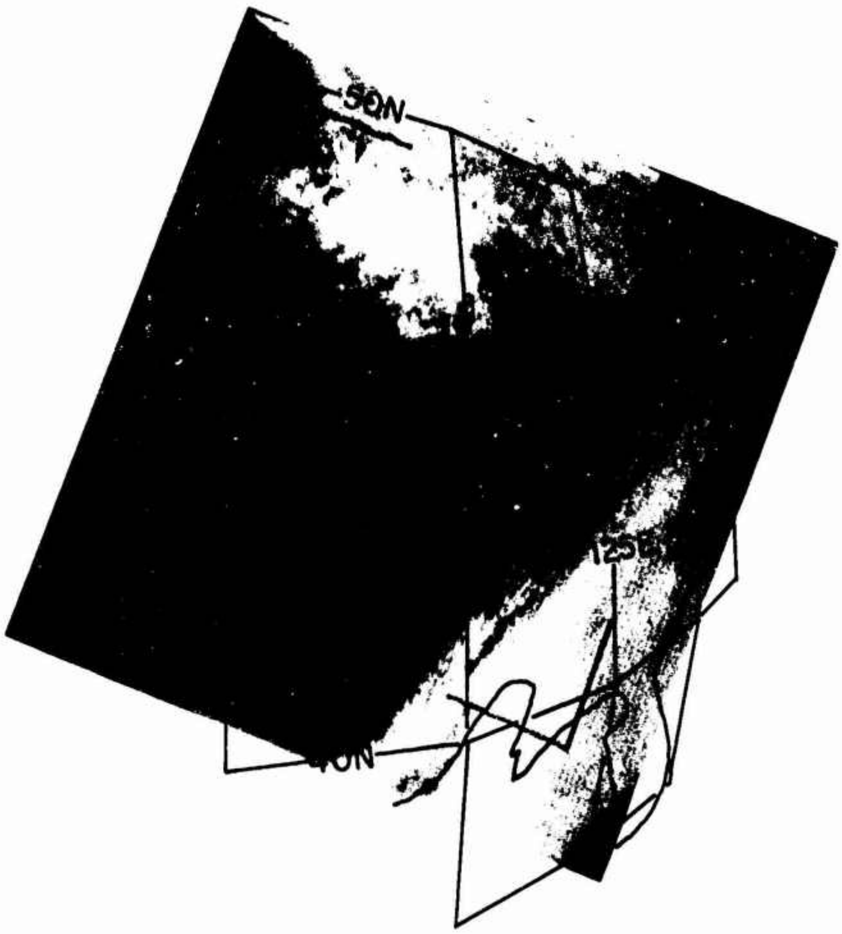
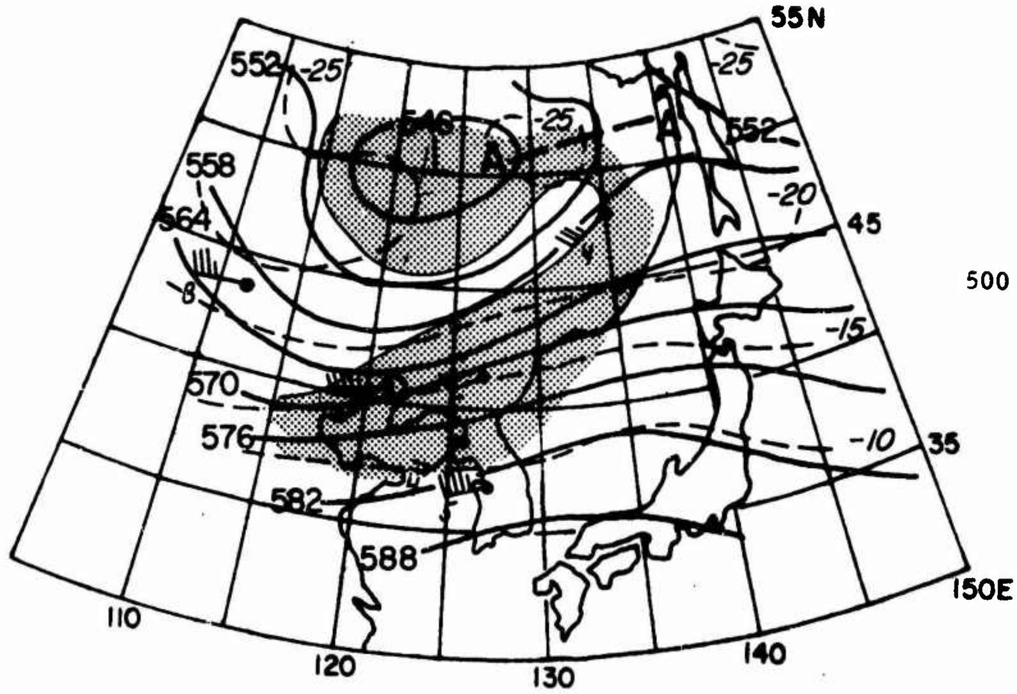
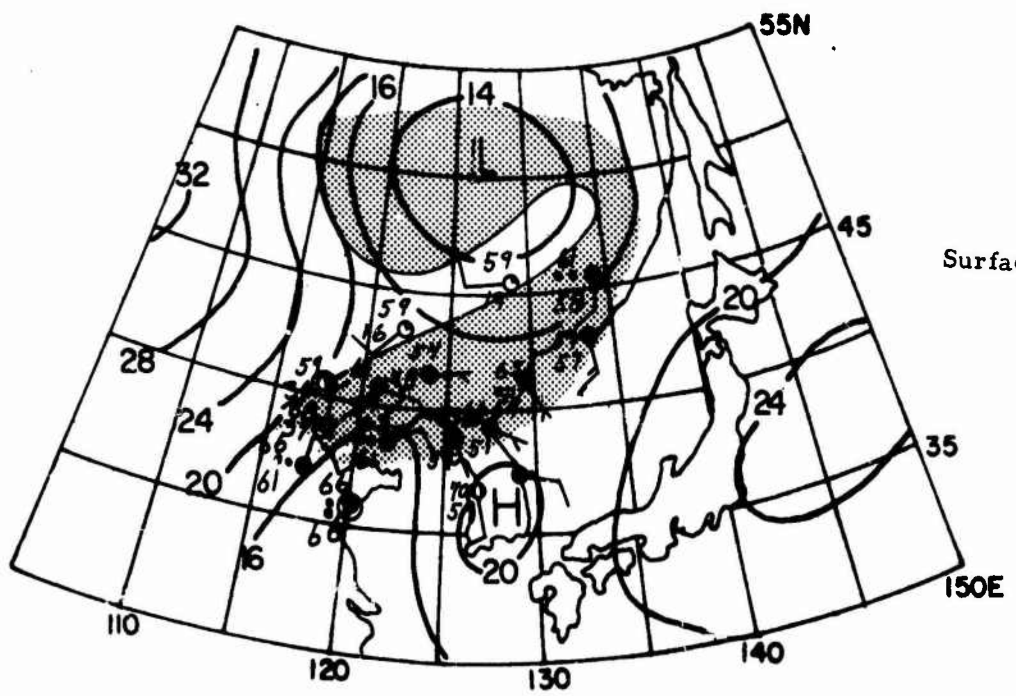


Fig. 3-22 TIROS VIII Photograph, Orbit 4173/4173, 0624 GMT, 4 October 1964.



500 MB



Surface

Fig. 3-23 500 mb Chart for 0000 GMT, 4 October 1964 and Surface Chart for 0600 GMT, 4 October 1964.

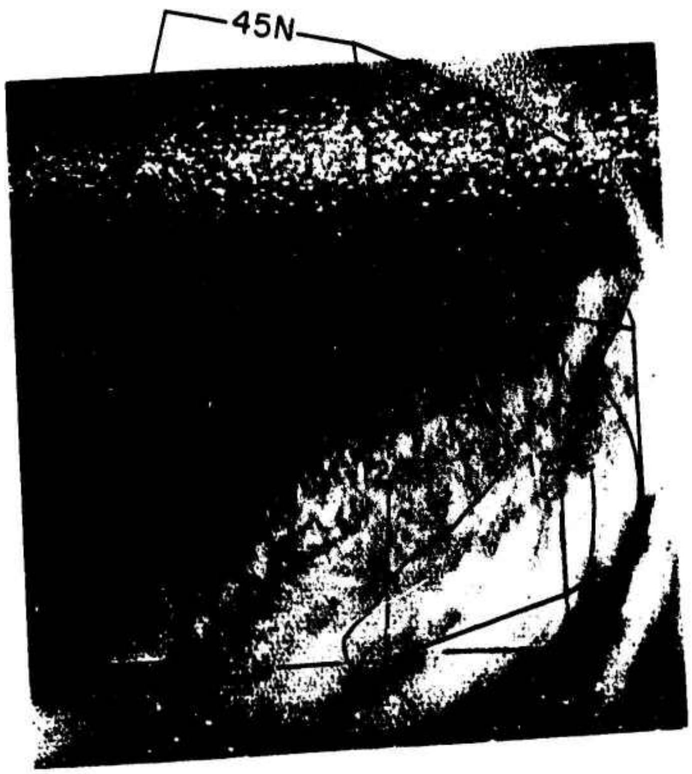


Fig. 3-24 TIROS VIII Photograph, Orbit 4187/4187, 0532 GMT, 5 October 1964.

At 500 mb at 0000 GMT (Fig. 3-25) the blocking situation has broken down and a broad trough is centered northwest of Korea. There is little indication of the short wave. The surface chart at 0600 GMT shows the low center to be filling near Sakalin, with a cold front across the Sea of Japan and Southern Korea. Some rain has been reported during the past hour in southeastern Korea, and skies are scattered to clear above North Korea.

From the satellite data, the clear area north of the cloud band could have been detected and predicted. With cloud cover over nearly all of Korea, it is unlikely that this could have been done in time of war with only limited conventional data and only limited or no reconnaissance north of the Yalu River. The significance to the Army of being able to predict the occurrence of a clear area for bombing or reconnaissance is obvious.

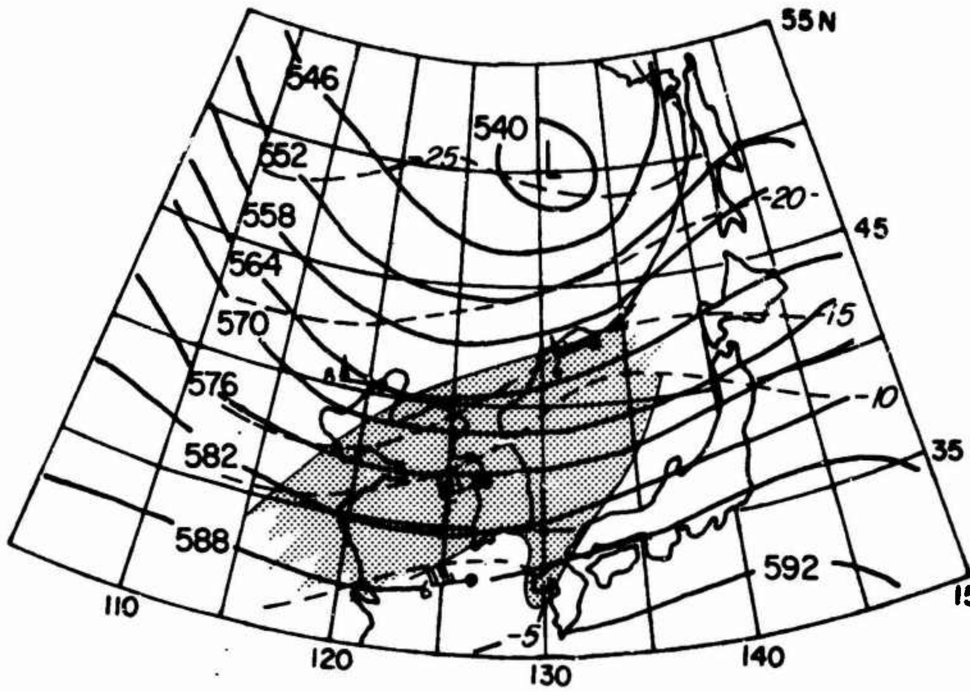
This four-day series of satellite observations demonstrates the uses that could have been made of such observations by the Army. Vital data was provided that could have been used to assist in detecting and predicting a weather system similar to systems affecting our forces in Korea during the autumns of 1950 and 1951.

3.4.4.2 General Discussion of Case II, 15-17 October 1964

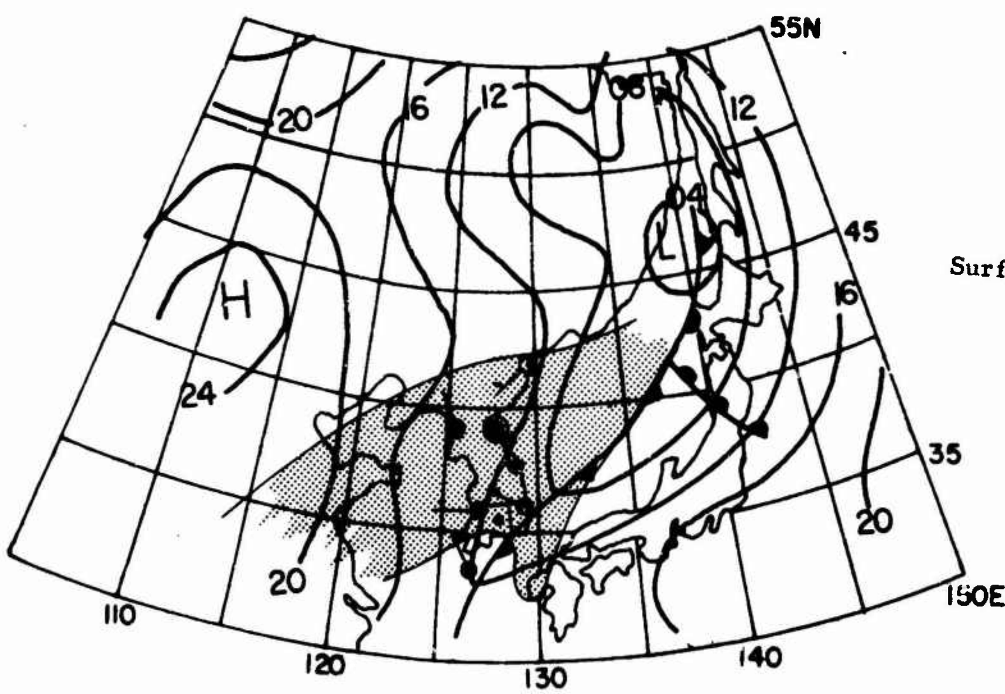
The satellite continued to provide useful information, and toward the middle of the month, another situation occurred where the satellite provided data that could have been extremely useful to the Army under war conditions. A short amplitude wave in the 500 mb flow, associated with a surface development, moved to the north of Korea. The frontal band is seen in the satellite pictures as it moves toward and across Korea with a probable wave developing on the front nearly over the Korean Peninsula. On 17 October, satellite data show the cloud band to be broken over Korea, although conventional data would lead to the assumption that the (frontal) band extended unbroken through the region. Again, a knowledge of the actual cloud pattern would be a vital asset to the Army in time of war.

3.4.4.2.1 Case II, Satellite Data

Satellite pictures of the Korean region are shown in Figure 3-26 for October 15, 16, and 17, at about 0000 GMT of each day. On the 15th, an apparent frontal band lies northwest of Korea in what would be a silent data area. The band is fairly

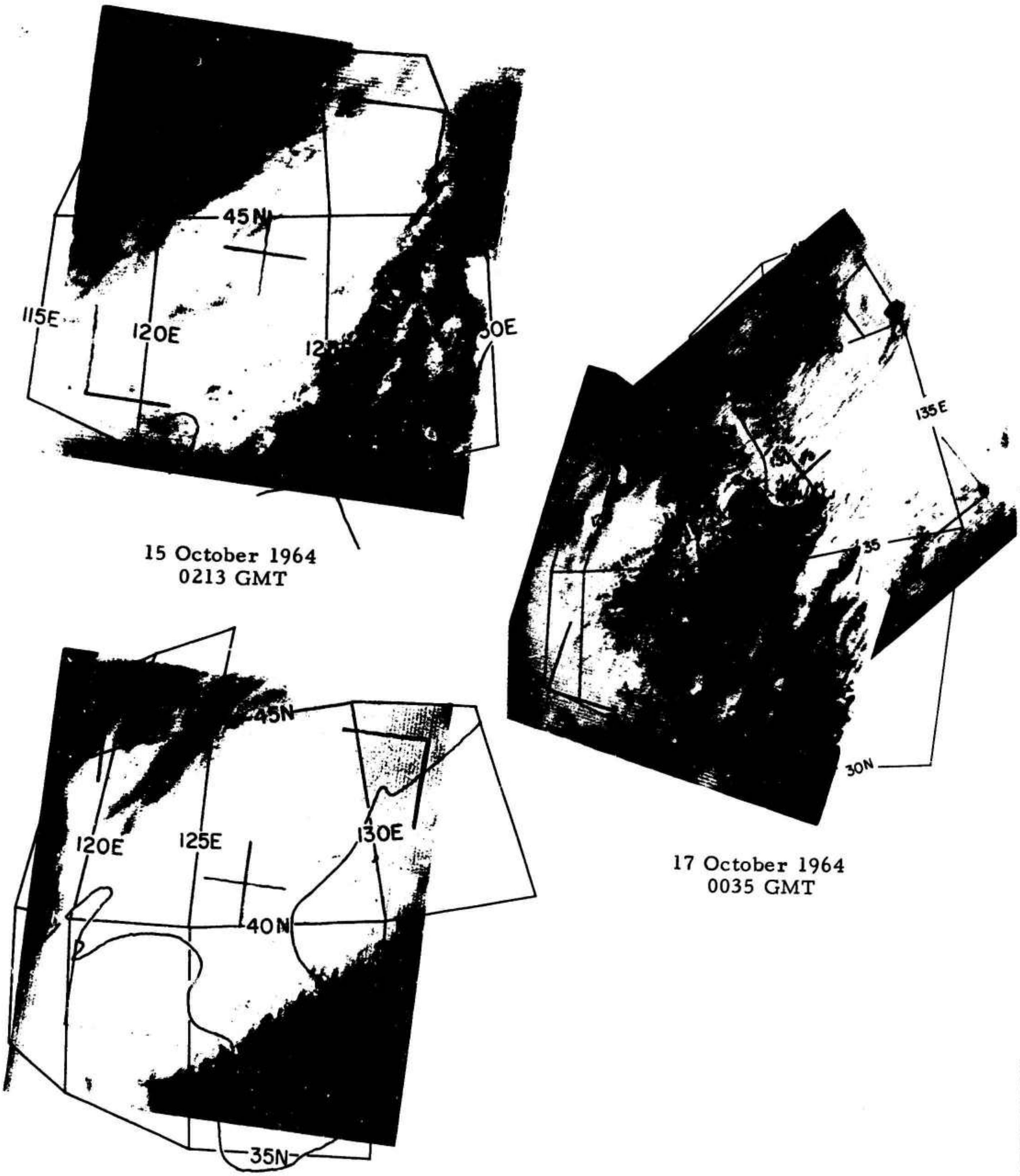


500 MB



Surface

Fig. 3-25 500 mb Chart for 0000 GMT, 5 October 1964 and Surface Chart for 0600 GMT, 5 October 1964.



15 October 1964
0213 GMT

17 October 1964
0035 GMT

16 October 1964
0124 GMT

Fig. 3-26 Three-Day Satellite Coverage of Korean Area

solid and bright, indicating that it is associated with a well developed frontal zone and probably some mid-tropospheric vertical motion. From experience with other similar cloud bands in this region, a movement toward the southeast could be anticipated which would bring clouds and precipitation to Korea.

On the following day, the cloud band is observed to be over Korea, with a well-defined leading edge and a solid, bright appearance. The extreme brightness of the cloud cover west of 130^{o} indicates enhanced vertical motion and a probable wave development on the surface front.

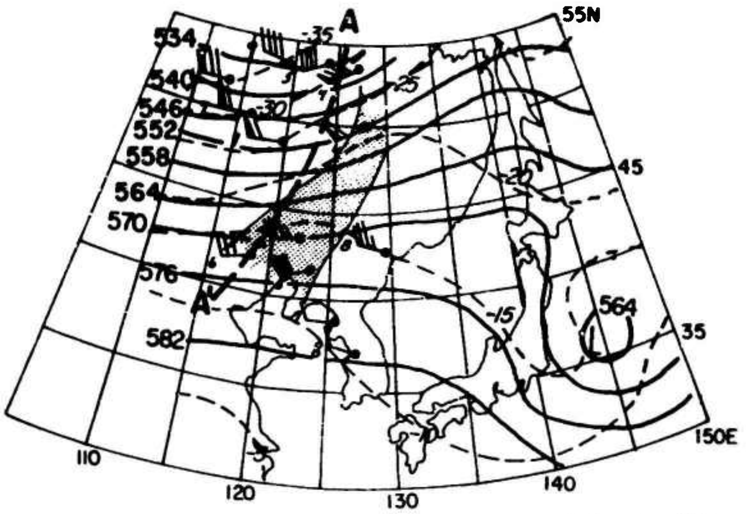
Finally, on the 17th, the remains of the band lie across Korea but with a mostly open area directly over the Korean Peninsula. There are a few wave clouds in this area, but much of the area is cloud free. This open area is probably due in part to a terrain effect.

3.4.4.2.2 Case II, 500 mb Data

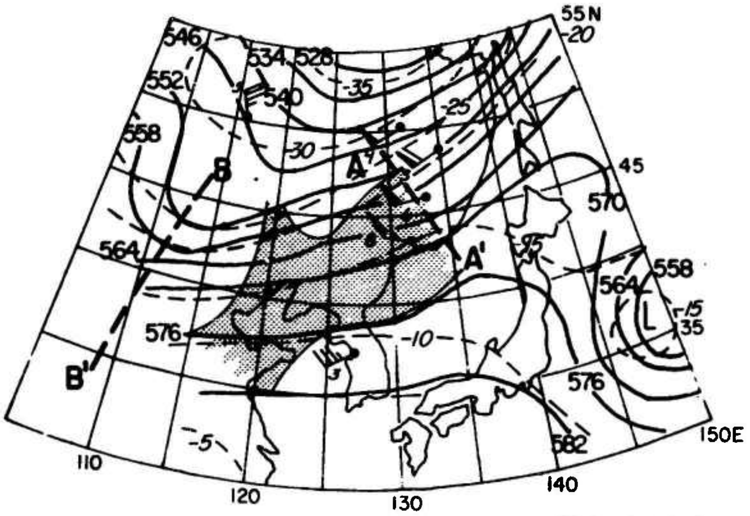
The 500 mb charts for 0000 GMT of each of the three days are shown in Figure 3-27. At this level on the first day, a broad trough is centered north of Korea. The reported winds indicate a short wave moving in the flow, from about 50N, 125E southwestward through 45N, 120E (line AA', top of Fig. 3-27). The cloud band lies just east of this line.

On the following day, the main trough has moved eastward with a second short wave dropping southward to the west and northwest of Korea (line BB'). The previous short wave (line AA'), apparently lies along the line AA' (center of Fig. 3-27) just east of North Korea.

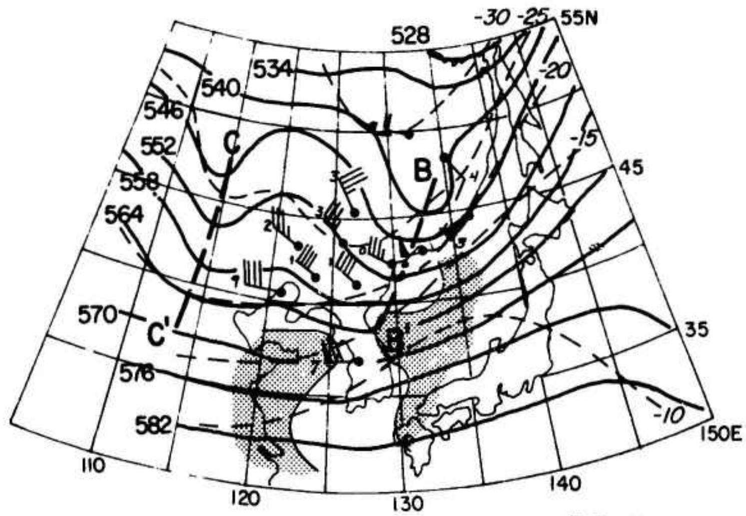
Twenty-four hours later, the vigorous short wave that had been to the northwest of Korea has moved rapidly eastward to a position over eastern Manchuria (line BB', lower part of Fig. 3-27). A small ridge has developed over or just west of Korea as a result, and probably helps to account for the observed break in the cloud band. It has been found that bands of this type generally become broken in or just west of the trough line (Reference 35). The western part of the cloud band may be associated with yet another short wave just northwest of Korea (line CC'), lower part of Fig. 3-27).



15 October 1964



16 October 1964



17 October 1964

Fig. 3-27 500 mb Charts for 0000 GMT, 15, 16 and 17 October 1964.

3.4.4.2.3 Case II, Surface Data

Surface charts for 0000 GMT of each day are shown in Figure 3-28. On the 15th, a weak wave is centered to the north of Korea with a cold front drawn from the center toward the southwest. The outline of the cloud pattern as seen in the pictures (Fig. 3-26) have been added to these maps for reference. Note how the satellite data clearly indicate the position of the frontal system which in areas of sparse data would be nearly impossible. A day later, the wave has deepened and is now centered near Sakalin with a front lying parallel to the coast and crossing North Korea. On this chart, there is some indication of a frontal wave developing over Korea. Moreover, rain is being reported from nearly every station in northern Korea and nearby China for some distance behind the front, with the rain area coinciding almost exactly with the brightest satellite observed cloud area. The surface data, therefore, support the probability of a frontal wave development as observed in the satellite data. These two confirming bits of data would make users more confident of their prognosis of early stages of this system. Any meteorologist can testify to the difficulty in predicting the development of a frontal wave.

On the third day, a cold front is drawn through South Korea with the frontal wave having moved eastward over the Sea of Japan. In South Korea, some rain is reported on the east coast; broken to clear skies are reported to the north.

3.4.4.2.4 Case II, Summary

The situations discussed in Case II again demonstrate the value of the satellite in detecting a frontal band associated with a mid-tropospheric wave passing to the north, approaching Korea from the northwest. In this case, even though skies were nearly clear over South Korea (16 October), the satellite detected the existence of the cloud band over North Korea with the probable wave development occuring on the frontal band. Furthermore, with only the conventional data that would have been available to the Army in time of war, the extent of the cloud free area over Korea on 17 October could not have been determined.

3.4.4.3 General Discussion of Case III, 20-21 October 1964

Significant precipitation occurred over a large part of Korea on 20 October, as a result of a rapidly moving mid-tropospheric disturbance that passed directly

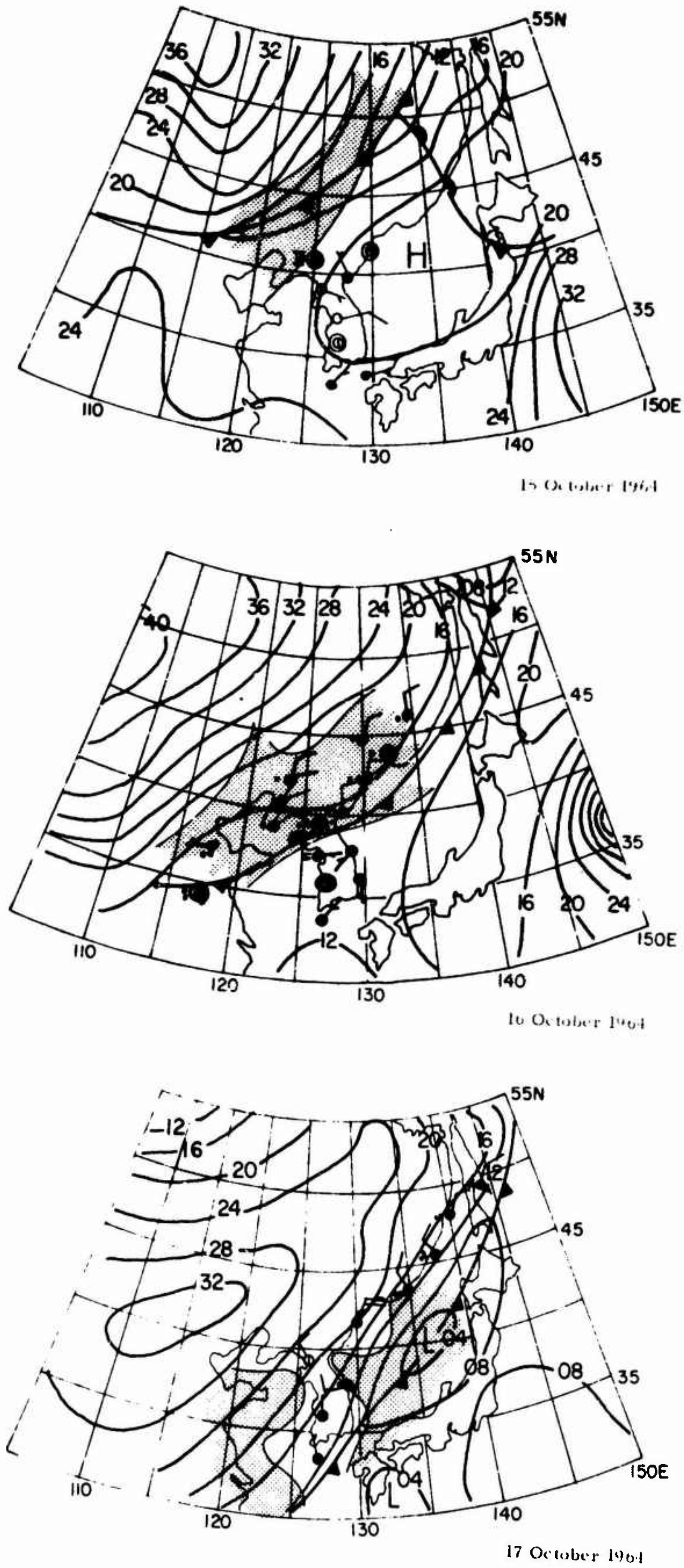


Fig. 3-28 Surface Charts for 0000 GMT, 15, 16 and 17 October 1964.

over the peninsula. Such rapidly moving disturbances are particularly troublesome to forecasters even where relatively abundant conventional data exist. The accurate detection and prediction of such disturbances often mean the difference between success or failure of an air drop of troops or supplies or of missions that depend on cloudiness for cover. Conventional data for 20 and 21 October give little indication of the cause of the precipitation, but satellite data for the same two days give a clear account of the situation.

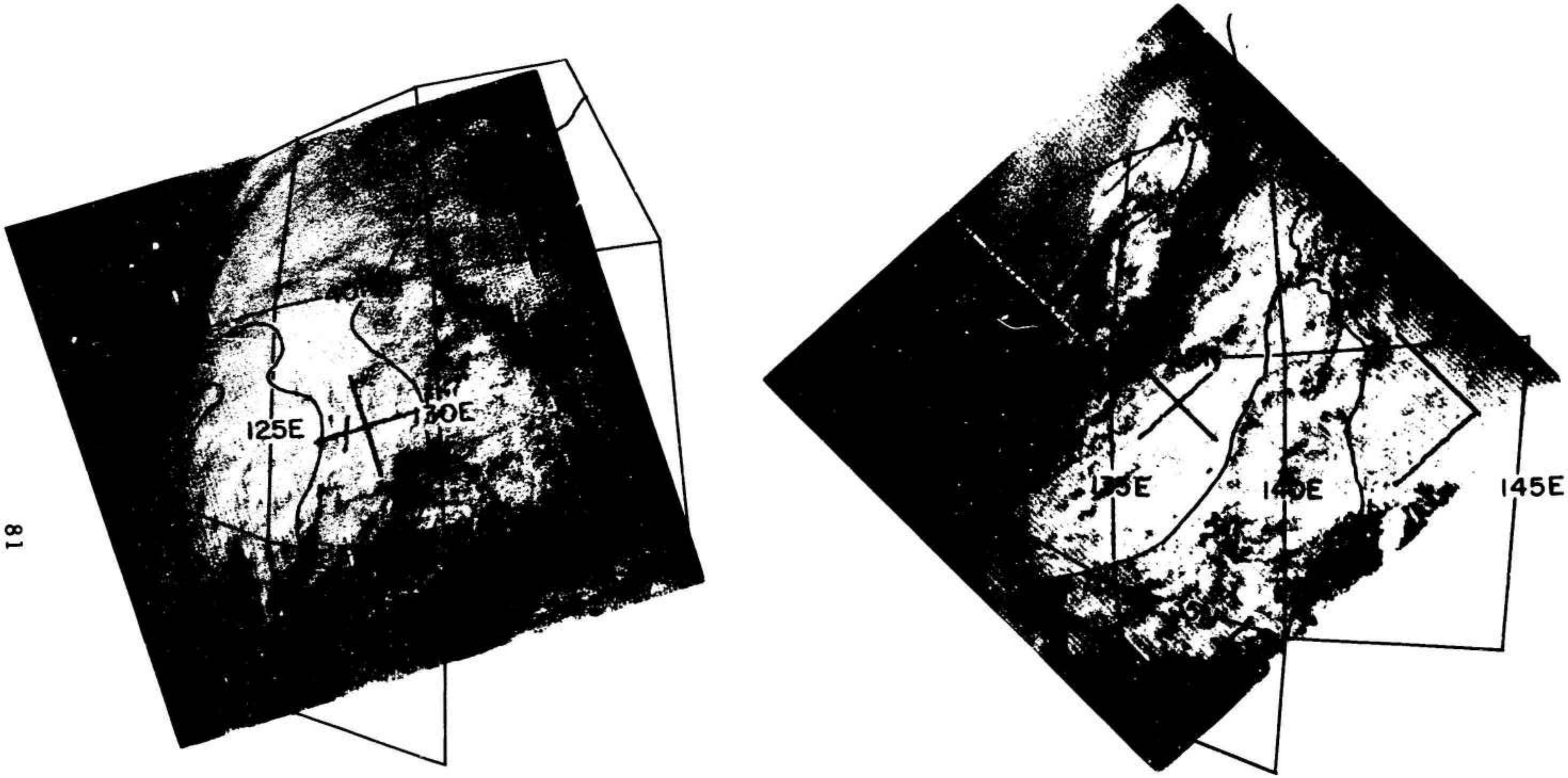
3.4.4.3.1 Case III, Satellite Data

Satellite pictures taken at about 0000 GMT of each day are shown in Figure 3-29. In the first picture, 20 October, a solid, bright appearing, and rough textured cloud mass is centered just west of Korea. Some of the cloud cover extends over Korea but the brightest clouds are to the west. There is some suggestion of a cyclonic circulation to this cloud pattern (especially near 40N between 120 and 130E). A cloud pattern such as this would most likely consist of clouds reaching to mid-tropospheric levels and would be expected to be associated with a short amplitude wave in the mid-tropospheric circulation. From the criteria for the probability of precipitation, discussed in Section 5, this pattern would be assigned a "Very Likely" probability of producing precipitation.

On the following day, a cloud mass with similar characteristics is observed to the east of Korea. Again the cloud cover is bright and has a "lumpy" texture, indicative of areas of higher cloud, with considerable vertical motion.

3.4.4.3.2 Case III, Conventional Data

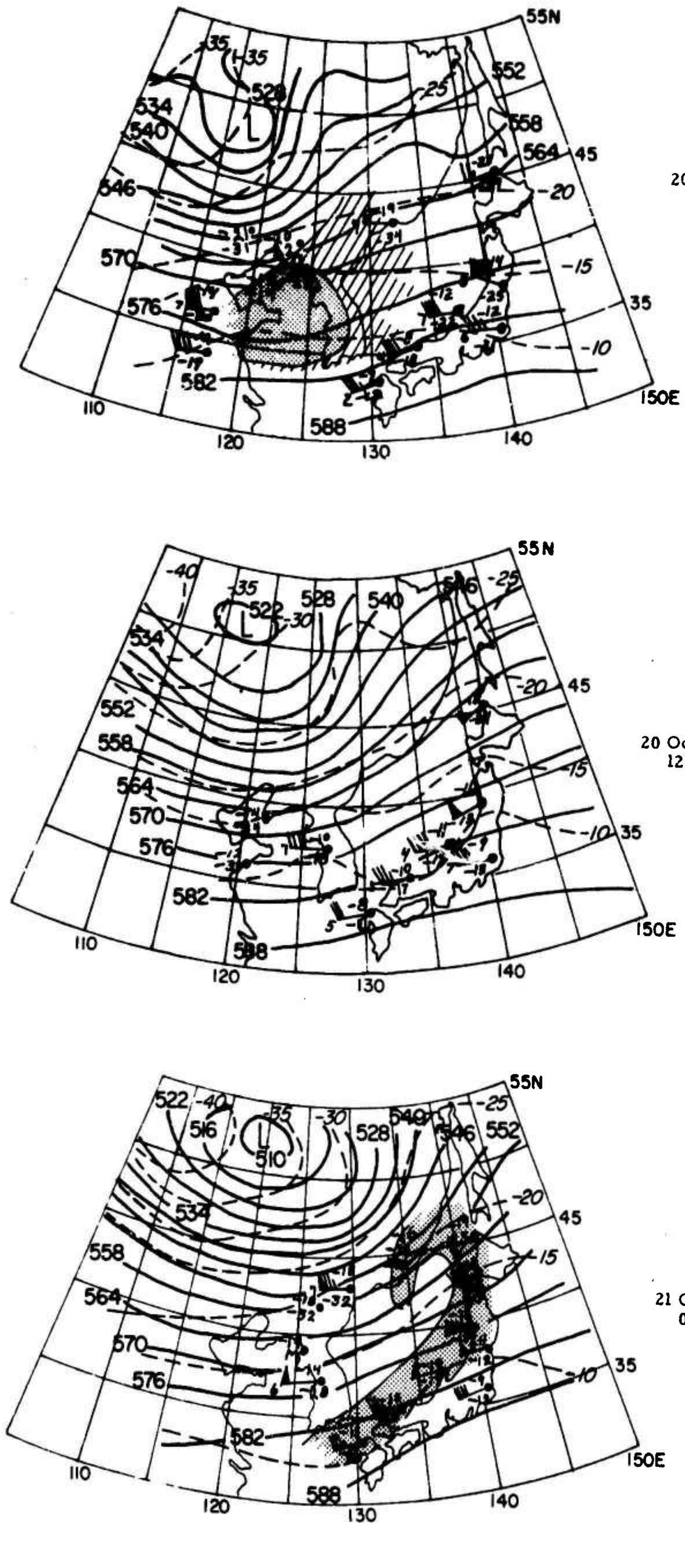
500 mb charts for each day are shown in Figure 3-30 and surface charts in Figure 3-31. In addition to the 0000 GMT charts, which are closest to the picture times, the 1200 GMT 500 mb chart for 20 October has been included for continuity. At 0000 GMT on 20 October, utilizing the rather sparse data, a short wave was drawn in the 500 mb flow to the northwest of Korea. There is little evidence of a disturbance just to the west of Korea, although the dew points at that level show the area to be near saturation. Also, a trough line could have been drawn southward from the low center and would lie just west of the area of the brightest cloud cover, as seen in the satellite picture for approximately the same time.



19 October 1964
2351 GMT

20 October 1964
2306 GMT

Fig. 3-29 Two-Day Satellite Coverage of Korean Area

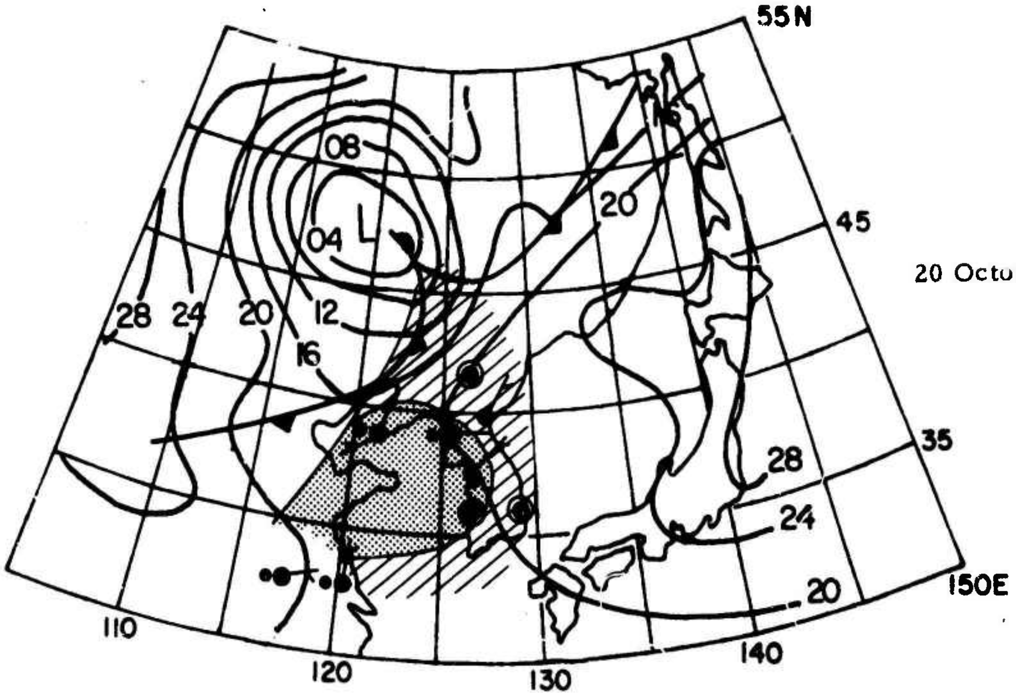


20 October 1964
0000 GMT

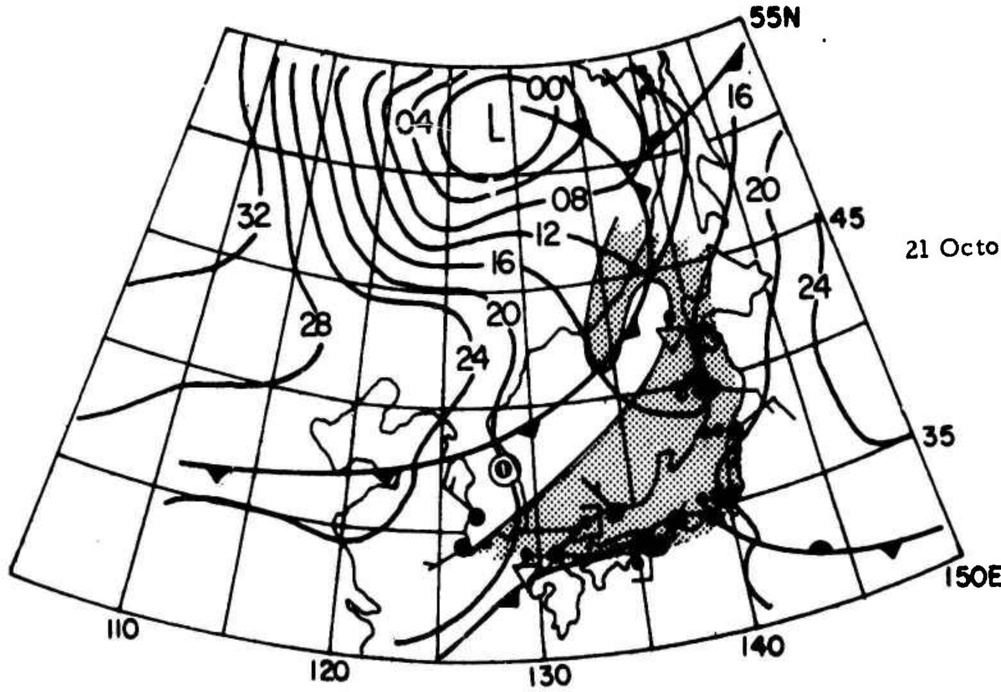
20 October 1964
1200 GMT

21 October 1964
0000 GMT

Fig. 3-30 500 mb Charts for 0000 GMT, 20 October 1964; 1200 GMT, 20 October 1964; and 0000 GMT, 21 October 1964.



20 October 1964



21 October 1964

Fig. 3-31 Surface Charts for 0000 GMT, 20 and 21 October 1964.

Twenty-four hours later, a major vortex has developed at 500 mb, with an increase in the gradient over the region. Again, the data give little indication of a short wave near Korea, but the winds over Japan have backed somewhat and the moisture has increased significantly at the Japanese stations.

In the interim period, at 1200 GMT on the 20th, midway between satellite observations, there again is little evidence of a short wave. A small wave could well be drawn just east of Korea, however, in the area of no data over the Sea of Japan.

The surface data show a low center well to the north of Korea with a cold front drawn through Korea on the 21st. Although no surface system is shown near Korea on the 20th, rain is reported at one station on the west coast and also to the west. On the 21st, considerable rain is being reported in Japan, well ahead of the indicated cold front. On both days, the area where rain is occurring is the area where the satellite shows the brightest cloud cover.

For purposes of continuity, surface charts for the interim period are included (Fig. 3-32). The charts show that rain is occurring over most of Korea at 0600 GMT and over southern and eastern Korea at 1200 GMT. At both times, surface data give no indications of the cause of the precipitation. By 1800 GMT, the rain has stopped over Korea (one east coast station reports that rain has ended during the hour), but rain has now broken out along the entire western coast of Japan. The rain area, therefore, is observed to progress eastward at the rate that would be expected from the observed movement of the cloud pattern in the satellite pictures.

3.4.4.3.3 Case III, Summary

In Case III, the satellite gives a clear indication of a rapidly moving rain-producing system that remains virtually undetected in the conventional data. During the Korean War, when data would have been missing completely from a large part of the region, the chances of detecting and predicting a system such as this would be extremely low. However, the precipitation from a system such as this can be significant to Army interests.

3.4.5 Summary of Cases

The three cases studied demonstrate that the satellite could have provided valuable data to the Army in Korea to aid in weather prediction during the difficult transition period between the summer and winter weather regimes. The first two cases

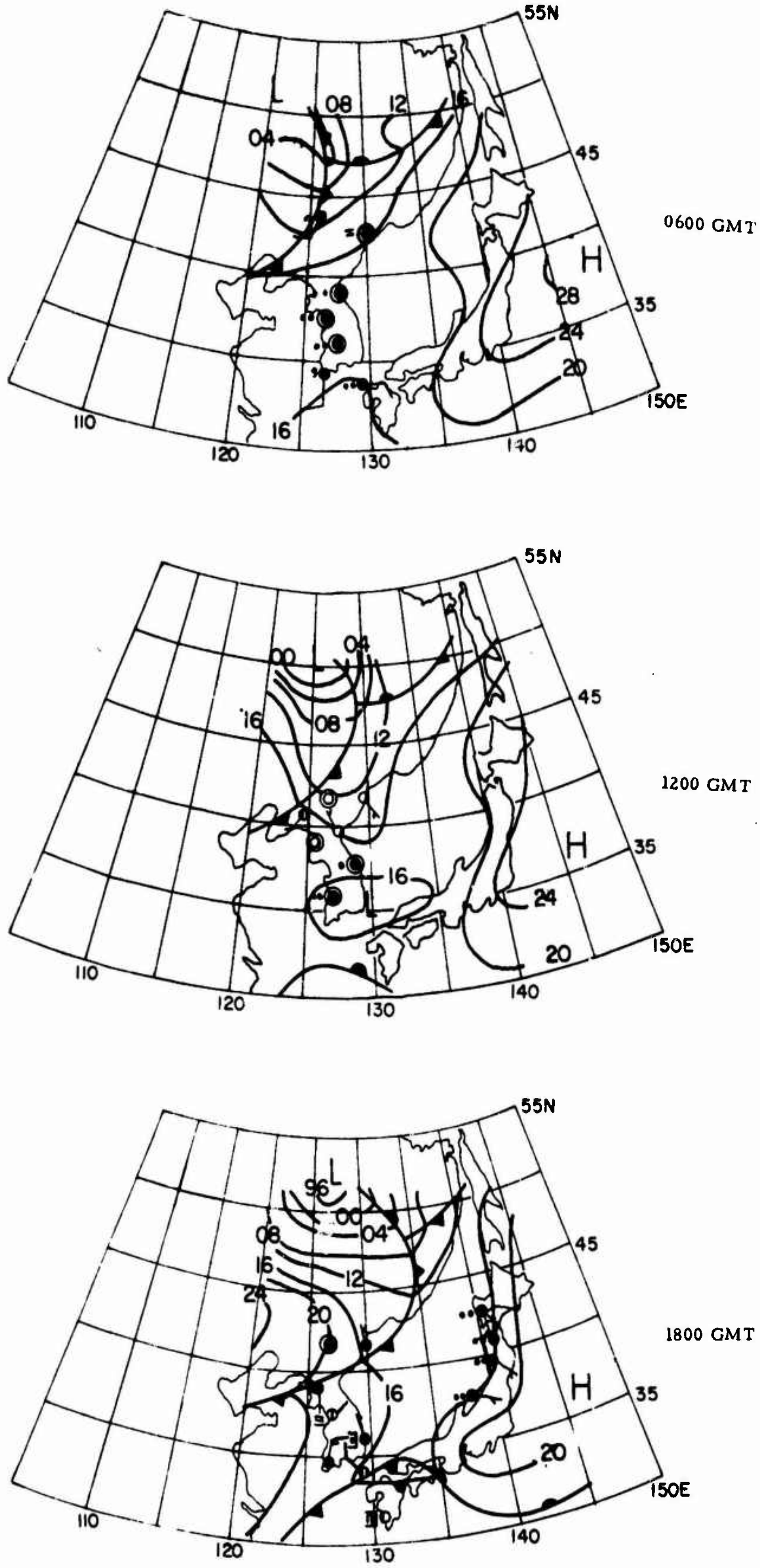


Fig. 3-32 Surface Charts for 20 October 1964, 0600, 1200 and 1800 GMT.

demonstrate the capability of the satellite to provide data on well-developed systems approaching Korea from the north or west. Moreover, in the second case, a probable frontal wave development over northern Korea was detected. In the third case, the satellite gave an indication of a significant system that developed rapidly and unexpectedly, nearly over the Korean Peninsula.

Although these cases were all from the same month, and so are analogous to Korean War situations that occurred during that season, the study indicates that the satellite would have been an invaluable data source to the Army in Korea for predicting similar and other situations occurring during other seasons.

3.5 Phase 3 - Army Maneuver in the Continental United States

3.5.1 Introduction

The previous case examples were necessarily based on analogs of certain aspects of weather conditions which were obtained during the campaigns studied. This case will demonstrate the applications of the satellite data for an Army field problem for which concurrent satellite data actually exists. This concurrence of actual data, together with the relatively good documentation of the non-meteorological aspects of the maneuver, make possible an emphasis on the subsynoptic or near mesoscale uses that can be made of the satellite data; something that was regrettably not feasible in the previous cases. Thus, demonstrations of the use of the data in support of tactical, rather than strategic, decisions are possible.

The case chosen is nicknamed "JTEX Gold Fire I," and took place on and near Fort Leonard Wood, Missouri, from 26 October to 11 November 1964 (Reference 5). The discussion will include the general weather conditions prevailing throughout the test, as obtained from NMC weather maps and upper air data in the vicinity of the maneuver area (Fort Leonard Wood); and will discuss for each day the additional data that can be obtained from the satellite pictures. It will be shown that some of the same types of synoptic information that can be obtained from the large amounts of conventional data available in the U. S. can also be obtained from the satellite data alone. For example, on at least two of the days during the maneuver period, frontal passages were observed in the Missouri area (see Figs. 3-35 and 3-41). These frontal bands were clearly depicted in the satellite pictures and it will be shown that local wind changes, probable amounts of precipitation, and areas of clouds (both broken and overcast) could have been delineated.

In addition, examples are presented which demonstrate the use that can be made of the data in various combat environment modes such as (1) without significant other weather data, (2) integrated with only one or two radiosonde reports from the combat area (for this study it was necessary to assume that the Columbia, Missouri, radiosonde station is within the exercise area when in reality it is 50-75 miles to the north and that the surface data from Springfield are representative of the exercise area), (3) integrated with slightly less limited radiosonde and conventional data, and (4) integrated with all available data such as weather maps from weather centrals. The integration of the satellite data with field radar data was not possible, since radar data from the test were not available. Time and funds did not allow the data from Kansas City (the nearest conventional weather radar site) to be obtained for use. However, examples of the integrated use of the satellite, conventional and radar data are presented in Section 4 of this report. The techniques presented there apply to field radar as well as to more conventional weather radar.

For the purposes of this demonstration of the value of satellite pictures to field Army prediction problems, pictures taken from the non-polar orbit TIROS series were those available for use. This presents problems of variation in nadir angles, requiring a higher skill in picture interpretation than is expected to be required for the polar orbiting ESSA (TOS) series and other weather satellites having APT systems. The polar orbiting satellites with APT systems will have the advantage that every picture will be taken as the camera is pointed nearly straight down. Thus, large distortions present in the earlier TIROS pictures, especially near the edges or horizons in the pictures, will not be present in APT pictures.

3.5.2 Objectives of JTEX Gold Fire I

The objectives of JTEX (Joint Task Force, Gold Fire I) was to "test and evaluate, for suitability in joint operations, procedures developed by the Air Force for using aviation to enhance the mobility and combat effectiveness of Army units." (Reference 5). Thus, by its very nature, exercise Gold Fire I required a maximum usage of aviation both for mobility of combat troops and for support of such units. In addition, the feasibility of close air support in this highly mobile environment was also demonstrated. It is not the object of this research to comment or report on the capabilities or results of such an exercise, with regard to the effectiveness or lack thereof, of any of the objectives being tested and evaluated. It is, however, the object of this research to indicate how the satellite data could have

been used by Army or supporting personnel in preparing weather data (present or predicted) for use by this air mobile operation.

As background for the discussions which follow, the organization of the task force will be outlined in brief.

Two opposing combat groups were organized (hereinafter referred to as Ozark Forces and Sioux Forces). Since the documentation describing the exercise may not be readily available to readers of this report and since the items in the exercise scenario are relevant to a discussion of the associated weather dependent operations, amended excerpts from the exercise scenario (Reference 5) follow:

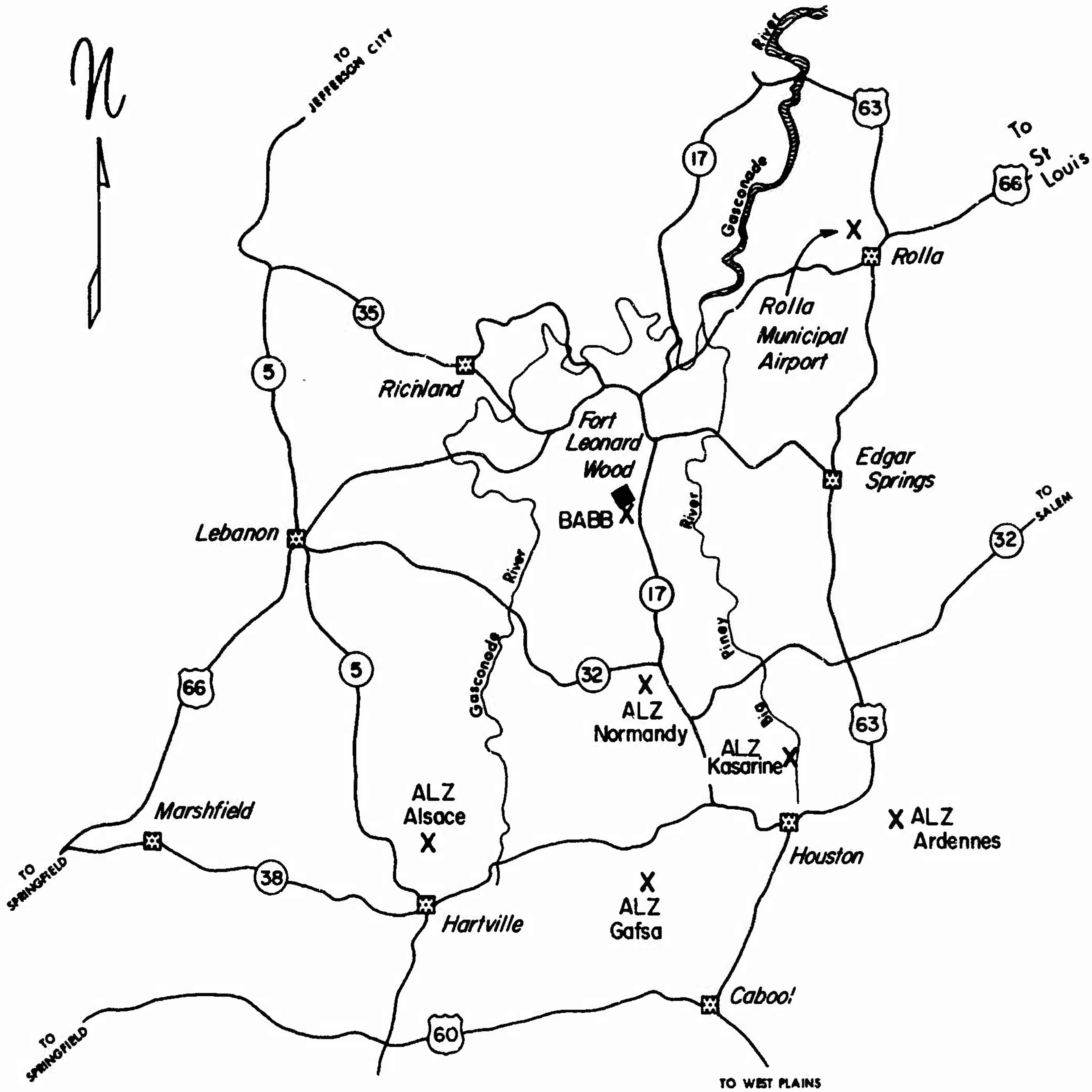
1. Phase I - Deployment

(a) On 27 October 1964 the initial deployment of JTF OZARK Army Forces (ARFOR) into the Exercise area began. Utilizing C-130 aircraft, quartering parties, engineer survey parties, and Army airfield control parties were delivered into an assault strip (BABB) at Fort Leonard Wood, Missouri. These advance parties were to survey prospective air landing zones, reconnoiter the initial assembly area, and coordinate and control the arrival of the main body of ARFOR OZARK into three landing fields commencing on 29 October 1964.

(b) The strategic deployment of ARFOR OZARK main body began at 0800 hours on 29 October 1964, approximately six hours behind schedule due to ground fog and weather conditions at departure airfields. ARFOR forces were deployed into three landing zones in the vicinity of Fort Leonard Wood, Missouri; Rolla Municipal Air Field in Rolla, Missouri; Edgar Springs assault strip approximately 15 miles east of Fort Leonard Wood proper; and Babb assault strip on the military reservation (see Fig. 3-33). Oversized equipment was delivered by MATS aircraft into Walnut Ridge Air Force Station (inactive), approximately 120 miles southeast of Fort Leonard Wood (see Fig. 3-34). This equipment (210 vehicles) and accompanying personnel was moved into the Exercise area overland.

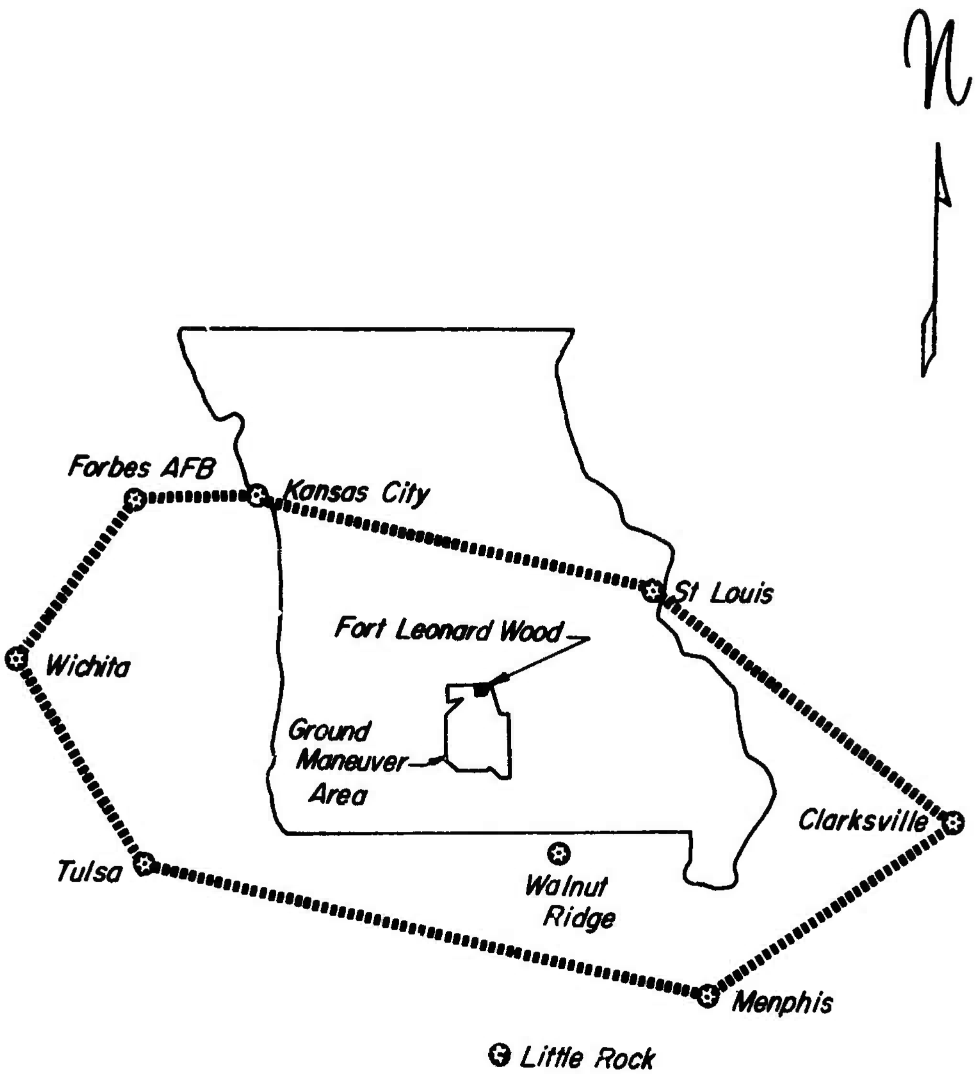
(c) Upon arrival in the Exercise area, units with their equipment, were moved in convoy to an intermediate holding area where unit integrity was regained. They then dispatched under tactical escort to the initial assembly area near Roby, 20 miles distant.

(d) By 1 November 1964, all ARFOR OZARK units and equipment programmed for the initial phase of the exercise had been delivered into the exercise area. A total of 581 TAC (C-130) and MATS sorties (C-124, C-133, C-130) were



Marshfield – Houston · · · 65 mi.
Richland – Cabool · · · · 70 mi

Fig. 3-33 Map of Ground Maneuver Area.



Clarksville - Wichita	490 N. Mi
St. Louis – Menphis	225 N. Mi
Kansas City - Tulsa	190 N. Mi
Ft. Leonard Wood - Walnut Ridge	100 N. Mi

Fig. 3-34 Map of Air Maneuver Area.

flown delivering a total of 4,114 personnel and 5,863 tons of supplies and equipment.

2. Phase II - Counterinsurgency

(a) JTF OZARK forces were disposed in an initial assembly area, approximately in the center of the Exercise area, with the mission of being prepared for counterinsurgency operations and assisting the friendly country of OROLAND in external security.

(b) A 300 man enemy guerrilla force was active in this phase of the Exercise with the mission of ambushing convoys, attacking facilities and installations, and presenting OZARK forces with a counterguerrilla requirement.

(c) ARFOR OZARK constructed one assault landing zone in the initial assembly area for use by C-130 aircraft and one additional assault landing zone for contingency operations. Organic Army engineers were used to construct these ALZ's.

(d) Re-supply of ARFOR forces was conducted employing the Air Line of Communications (ALOC) concept. Good weather, both at the supply base and at the ALZ's, was critical to the success of such re-supply missions. Supplies, personnel, and equipment were delivered into the assault landing zone within the initial assembly area employing C-130 aircraft. Supplies (Class I, III, and V) were delivered by multiple means (air landed, heavy drop, ground proximity extraction system, and parachute low altitude delivery system) from the Log Base to the forward area.

3. Phase III - Movement to Contact and Delay

(a) Under the indicated threat of attack by JTF SIOUX forces (Argentian), JTF OZARK employed a portion of his combat forces along the international boundary as a screening element.

(b) On 4 November 1964, JTF SIOUX forces attacked on the ground and in the air. Employing delaying action tactics and utilizing both Army and Air Force air mobility means, JTF OZARK began withdrawing his forces along successive delaying positions. Maximum utilization was made of AFFOR OZARK tactical air in support of this operation.

(c) JTF OZARK withdrew his forces east of a natural obstacle, the BIG PINEY RIVER, with the purpose of halting the advance of JTF SIOUX forces along this line.

(d) In order to halt the attack of JTF SIOUX forces and to be prepared to conduct a counter-offensive, JTF OZARK requested reinforcements of both

ARFOR and AFFOR forces. The airlift of such reinforcements depended on favorable weather in the maneuver area. JTF OZARK was reinforced with one additional Infantry Battalion (1/18 Inf) and one additional fighter squadron on 5 November 1964.

(e) By the end of this phase, JTF OZARK was in position east of the BIG PINEY RIVER with JTF SIOUX holding small bridgehead crossings over the river.

4. Phase IV - Defense

(a) On 6 November 1964 parity existed between opposing ground and air forces. JTF OZARK had the mission of defending the capitol city of HOUSTON and of holding JTF SIOUX forces west of the BIG PINEY RIVER.

(b) In a series of limited objective attacks, JTF SIOUX succeeded in expanding his bridgehead crossings over the BIG PINEY RIVER and was threatening the city of HOUSTON.

(c) On 7 November 1964 JTF SIOUX succeeded in conducting a surprise attack under the cover of inclement weather which minimized JTF OZARK air power, turned the north flank of JTF OZARK, and cut off the city of HOUSTON from the northeast. This turning movement was in conjunction with attacks against ARFOR OZARK units from the west across the BIG PINEY RIVER. The single available OZARK ALZ was brought under 105-mm artillery fire by attacking SIOUX forces. A forecast of improving weather at the ALZ's to allow the airlift of additional support was critical.

(d) Early in the morning on 7 November 1964, the 2/506 Inf (ABN) was deployed into an assault landing zone east of HOUSTON. At 0930 hours on 7 November this unit was placed under brigade control to assist in halting the advance of JTF SIOUX forces and to force him to withdraw his forces west of the BIG PINEY RIVER.

(e) By the end of the day on 7 November 1964, JTF OZARK had been unsuccessful in ejecting SIOUX forces and in forcing his withdrawal west of the BIG PINEY RIVER.

(f) On the night 7-8 November 1964, Maneuver Director Headquarters ordered JTF SIOUX to withdraw his forces from around HOUSTON and establish defensive positions west of the BIG PINEY RIVER. This withdrawal was completed 0200 hours 8 November 1964.

(g) On 8 November 1964, JTF OZARK repositioned his forces and established a defense of the BIG PINEY RIVER. Combat losses of personnel and equipment were replaced, units were re-supplied by air and ground means, and plans were developed for initiation of offensive operations on 9 November 1964.

5. Phase V - Offense

(a) At 0001 on 9 November 1964, JTF OZARK launched his counter-offensive to destroy JTF SIOUX forces and to reconstitute the international border between the two countries.

(b) Employing ground attack, air attack and air mobile operations, JTF OZARK forced the withdrawal of SIOUX forces to positions approximately 40 kilometers from the international boundary by the end of the day on 9 November 1964.

(c) Employing organic engineers, JTF OZARK reconstituted assault landing zones which had been constructed during earlier phases and which had been destroyed by JTF SIOUX during his advance. Use of one of these landing zones permitted JTF OZARK to keep his forces supplied through the ALOC and to displace his logistical and support elements forward into a Forward Operating Base (FOB) by C-130 aircraft.

(d) JTF OZARK continued the attack against deteriorating SIOUX forces employing air-mobile operations and ground and air attack to force the withdrawal of all JTF SIOUX elements across the international boundary.

(e) Upon seizure of final objectives along the international boundary on 11 November 1964, Joint Test and Evaluation Exercise GOLD FIRE I was terminated.

With this discussion as background, the synoptic conditions on a day-to-day basis will be discussed, using the available satellite data to supplement the conventional data and, where desirable, to indicate the data that could have been obtained from the satellite pictures in lieu of the conventional data available for this exercise.

3.5.3 Discussion of the Synoptic Situation

Although the actual deployment of the JTF Ozark Army Forces into the exercise area began on 27 October 1964, preparations and early movements of men and materials were begun approximately 25 October 1964.

During the period 25 to 26 October 1964, supplies and personnel of the main force were being organized for a simulated 2200 mile flight from Fort Riley, Kansas, and Forbes AFB into the maneuver area near Fort Leonard Wood. The quartering and survey parties departed on 27 October 1964, but the main deployment (air lift) was scheduled for 0200 GMT, 29 October 1964, from Kansas. This main deployment was delayed more than six hours by adverse weather which took the form of low ceilings and showery precipitation. This weather situation is a typical example of a type which is frequently not adequately predicted even using the relatively dense conventional data available to the field forecasters in the United States. For such a planned operation, forecasters would have been concerned with preparing forecasts for deployment time starting at least as early as 26 October 1964.

The first examples of the use of the satellite data for a field operation will begin on 26 October 1964. They will indicate how the weather personnel actually faced with forecast problems for this exercise, could have integrated the satellite data with the relatively abundant conventional meteorological data available in the central United States, to provide a better description of the current weather and, hence, better predictions. Discussions for later periods of the exercise will emphasize sparse data interpretation techniques.

3.5.3.1 The Synoptics of 26 October 1964

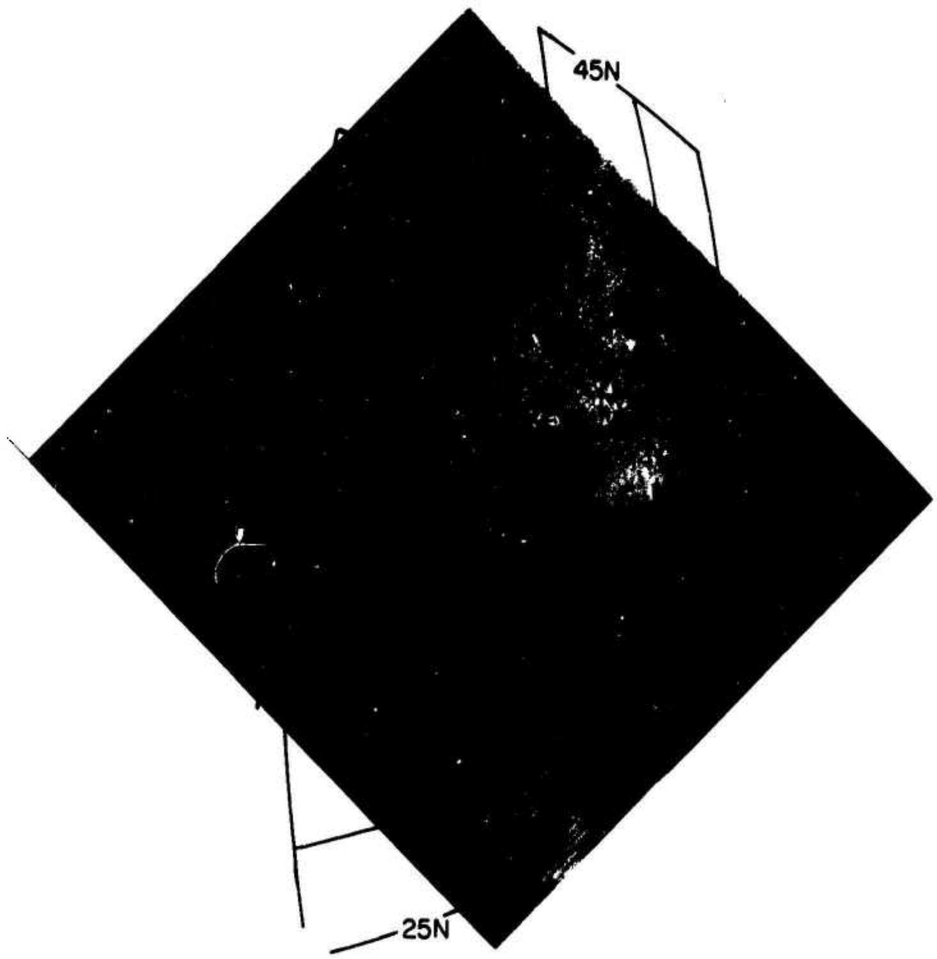
At 1200 GMT, overcast skies were reported over all of Missouri and eastern Kansas. Shower activity, presently in progress or occurring within the past hour, was recorded throughout eastern Kansas. Heavy showers had occurred in the maneuver area during the previous twenty-four hours.

No fronts were drawn on the 1800 GMT surface chart, but spotty areas of precipitation in extreme northwestern Iowa, southwestern Iowa, and eastern Texas were indicated. The area appears to be under the influence of northward flowing air on the rear side of the high centered over North and South Carolina. A satellite picture (see Fig. 3-35), taken at approximately 2147 GMT, showed a broken to overcast band extending generally north-south over Iowa, Missouri, and Oklahoma. The rear edge of the band is just passing the Fort Riley - Forbes AFB area. The band is broken to overcast and shows clear evidence of the buildup of cumulus-congestus type cloudiness in southern Missouri and northeastern Arkansas. A lower overcast is evident in more southern areas. Using the precipitation probability criteria detailed in Section 5 of this report, a probability of "Likely" would be assigned for precipitation

occurring with this cloud band north of 35°N. The ground in the maneuver area will be wet as a result of this precipitation. A more striking point to be noted in this picture is the relatively sharp western boundary of the band, now indicated to be over east central Kansas and central Oklahoma, with only scattered cumulus clouds in rather weak lines to the west (see Fig. 3-35). A rather crude calculation of the movement of the western boundary of this cloud, using a picture twenty-four hours earlier (not shown), indicates that the rear edge of this cloud band is moving eastward at a speed of approximately twelve to fifteen miles per hour. Since the western edge of the band is some 120 to 150 miles west of the maneuver area at this time, weather personnel might have forecast the persistence of the overcast, or perhaps broken, clouds for at least another ten to twelve hours. Showery precipitation (especially normal convective showers) would be likely. By 0600 GMT, 27 October 1964 (near local midnight), 1.83 inches precipitation had fallen in the maneuver area; 0.39 inches at St. Louis; and 0.22 inches at Kansas City. It would be difficult from the surface analysis alone (not shown) to deduce the cause for the synoptic situation which produced this weather. The integrated data, however, give a clear indication of the weather pattern in the maneuver area and the probable conditions for the next ten to twelve hours. This prediction was somewhat critical since advanced parties for quartering, engineer survey, and airfield control were to be delivered by air to the assault strip (BABB) at Fort Leonard Wood early on 27 October 1964.

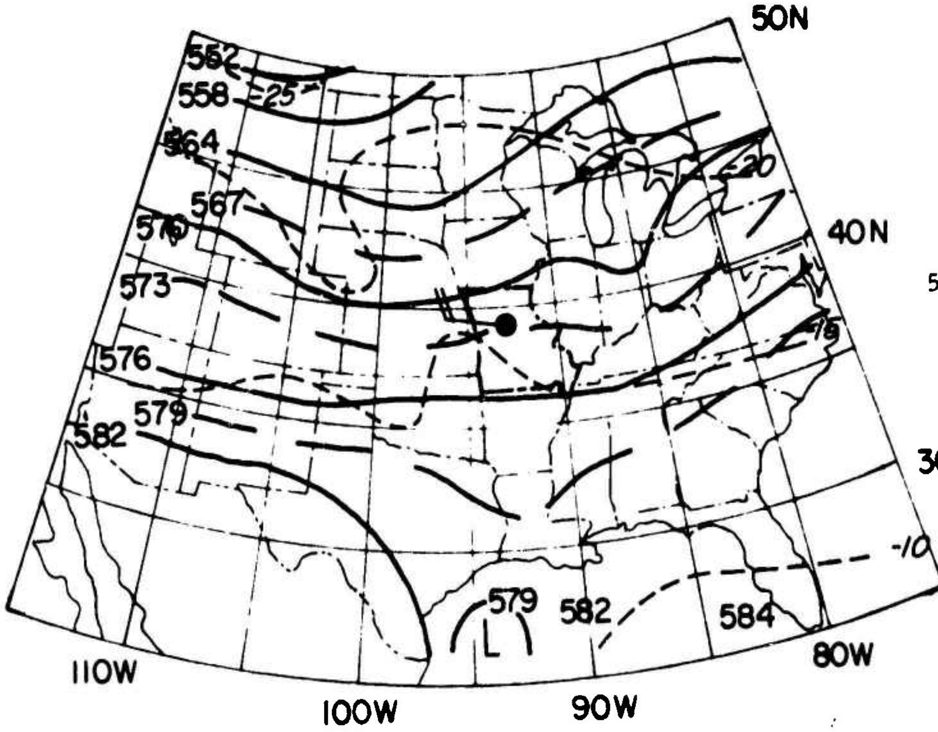
3.5.3.2 27 October 1964

At 0000 GMT, 27 October 1964, broken to overcast conditions were reported over most of Missouri with no indication of precipitation. The trough at 500 mb has weakened considerably and is now located over north central Missouri. The satellite picture (Fig. 3-35), by its lack of an organized crescent pattern, suggests that the 500 mb pattern was relatively weak. By 1200 GMT (0600 local), overcast skies with light winds were again indicated in Missouri with some light to moderate rain falling in southern Missouri. Local obscured skies with ground fog were observed at Kansas City and northward. The 500 mb charts show the original 500 mb disturbance, now south of Lake Michigan, to be moving rapidly eastward. A new trough is seen in the westerlies, centered over central South Dakota and extending into southwestern Nebraska. Cyclogenesis is occurring in the North Dakota-South Dakota region and a front now has been drawn on the surface chart extending through central South Dakota into southwestern Nebraska and then westward (see Fig. 3-36). The extent



● Kansas City
■ Ft. Leonard Wood
▲ St. Louis

Fig. 3-35 Satellite Picture of Midwestern United States, 2147 GMT, 26 October 1964. Note Cloud Band Across Missouri and Arkansas.



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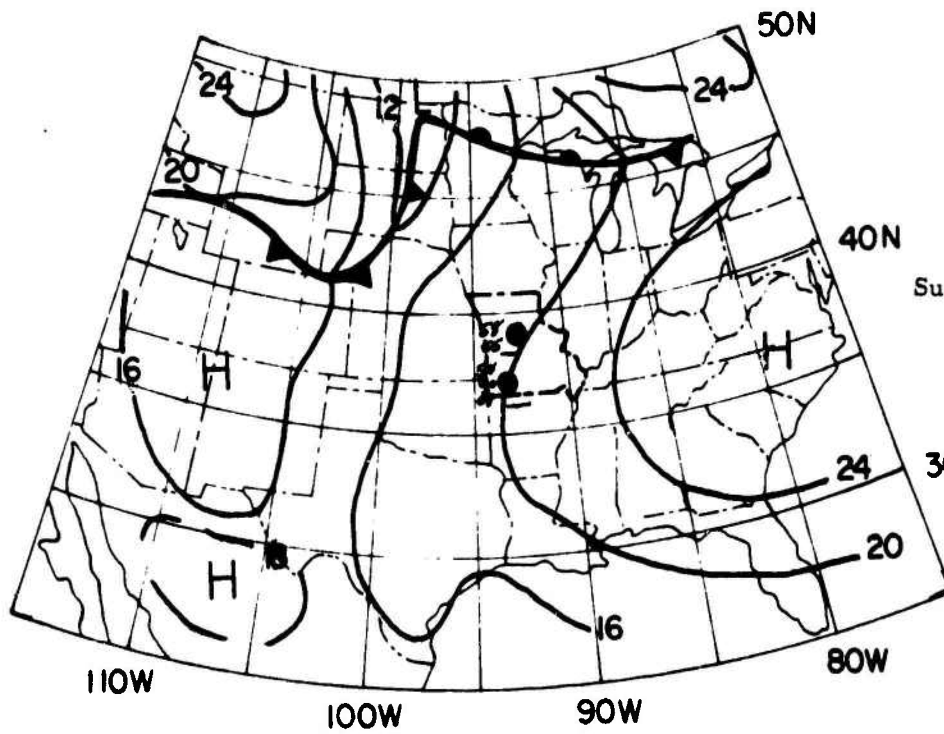


Surface

Fig. 3-36 Surface and 500 mb Charts for 1200 GMT, 27 October 1964.

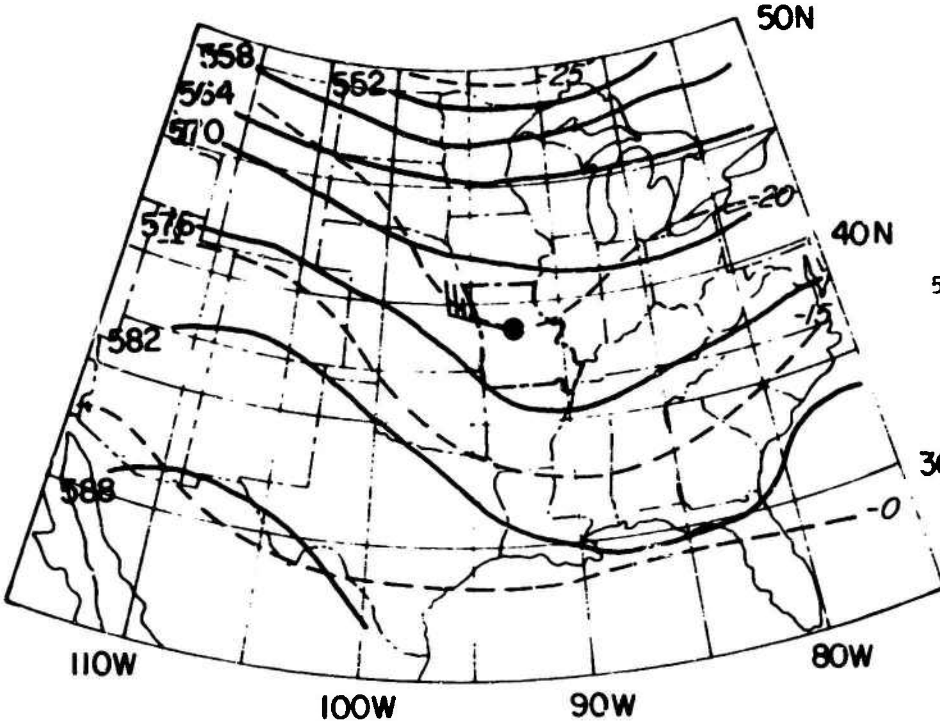
of cloudiness associated with this new disturbance is a critical parameter for forecasts for the next ten to twelve hours or longer.

By 1800 GMT (near local noon), the cold front is near the northwestern corner of Missouri, but little or no precipitation is indicated along this front. At about 2150 GMT, satellite pictures showing only the southeastern corner of Missouri were taken. At this time, a mostly covered (MCO) area was observed, indicating that some cloudiness still persists in southeastern Missouri.

3.5.3.3 28 October 1964

At 0000 GMT, the surface chart (not shown) indicated broken sky conditions in the northern, western, and southern parts of Missouri. A cold front indicated on the surface map was very near the northwest corner of Missouri, lying generally north-northeast, south-southwest. The uncertainty of the weather associated with this front was no doubt causing the user some problems. Kansas City was overcast at this time, but no precipitation was reported. At 500 mb, the trough lay generally along a line just west of Lake Michigan through the southeastern corner of Missouri into Arkansas. Large temperature dew point spreads at Columbia and west, indicated a low probability of cloudiness behind the surface cold front.

By 1200 GMT (0600 local), a prediction of expected weather conditions for the air deployment of the main body (scheduled for 0200, local, 29 October) was certainly a critical ingredient of the plans being finalized by commanders. A cold front lay generally northeast-southwest through central Missouri (see Fig. 3-37). St Louis reported scattered to broken clouds with light ground fog. All stations behind (i.e., northwest of) the cold front were showing scattered to broken cloudiness while along the front in Oklahoma, more fog was indicated. At 500 mb (top of Fig 3-37), the temperature-dew point spreads east of and generally in the trough were relatively small (approximately 3 to 5^{o}), while west of the trough 6 to 9^{o} dew point spreads were indicated, suggesting an expected probability of clouds in and to the east of the trough and probably some broken cloudiness west of the trough. The definition of the western boundary of this disturbance and its movement, becomes a critical prediction problem. Later surface observations at 1800 GMT only complicated the problem, since the surface analysis (not shown) indicated that the front had moved back northward to a nearly east-west position along the northern border of Missouri. Little or no precipitation was indicated.



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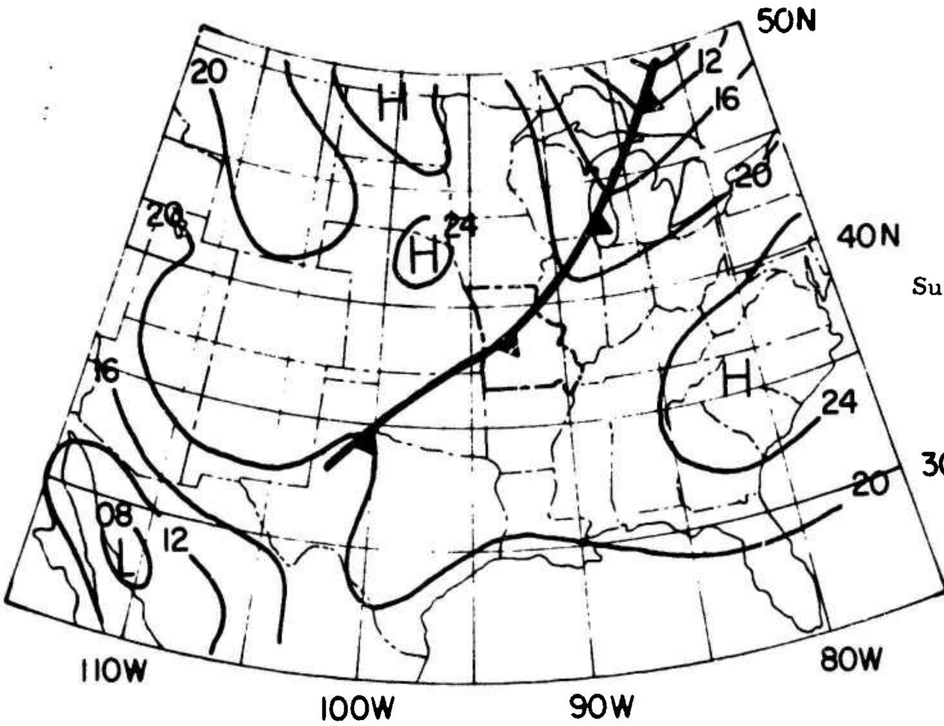


Surface

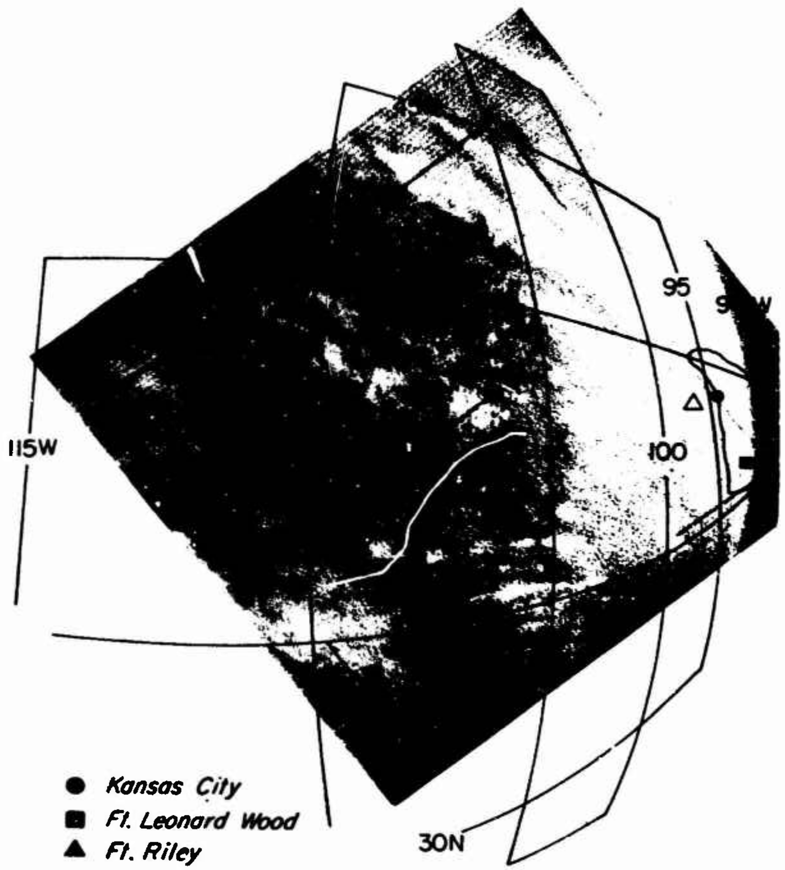
Fig. 3-37 Surface and 500 mb Charts for 1200 GMT, 28 October 1964.

Satellite pictures of the area were taken on two successive passes, at approximately 2010 GMT and 2150 GMT. Both passes have a high nadir angle in the Missouri area, but the easternmost pass indicated a cloud band lying generally north-south from the northern Missouri border into Wisconsin (see right side of Fig. 3-38). This northern band was associated with the short amplitude wave in the mid-troposphere, which was barely detectable in the 1200 GMT 500 mb map but was clearly evident in the map for 0000 GMT, 2° October 1964 (Fig. 3-39) along A-A. A weaker band lay generally east-west from central Missouri eastward. The band over eastern Missouri is mostly broken and gives little indication of any precipitation. The northernmost band was more solid and suggested a high probability of precipitation. From the picture (left of Fig. 3-38), the band over Missouri appears relatively bright, but the high nadir angle prohibits any positive statements to be made about the character of the band. (In APT pictures, such extreme nadir angle problems should not be encountered and a more positive interpretation would have been possible.) West of Missouri some less bright cloudiness is evident. Coupled with ground observations of low stratus and ground fog, the satellite data define the widespread nature of this foggy condition. For example, it appears that the fog is fairly uniform west of Forbes AFB to nearly 105°W and spotty further west. The slow movement of the frontal system and the usual diurnal effects suggest that this condition will prevail until a few hours after local sunup, or at least until about 0800 local time.

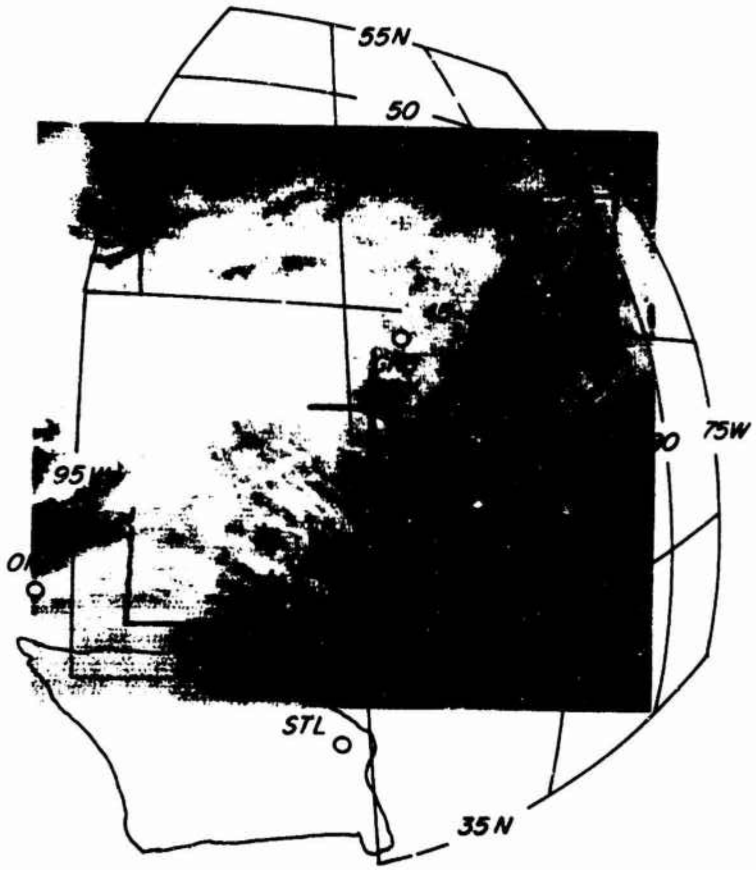
Precipitation recorded during the period from 0600 GMT, 28 October 1964, to 0600 GMT, 29 October 1964, showed only a trace in extreme southeastern Missouri, larger amounts to the south near Memphis, and relatively small amounts in the Wisconsin area.

3.5.3.4 29 October 1964

By 0000 GMT, 29 October 1964, the front had become nearly stationary, lying generally east-west across the northern portion of Missouri. Columbia, Missouri, Kansas City, and surrounding areas were experiencing overcast middle clouds but no precipitation at this time (Fig. 3-39). At 500 mb, Columbia, Missouri showed a moderate northwesterly flow, but to the north there is an indication of a short wave in the northwest flow (line A-A in Fig. 3-39). The cloudiness associated with this trough was clearly evident in the picture at 2010 GMT, 28 October 1964 (Fig. 3-38 top).

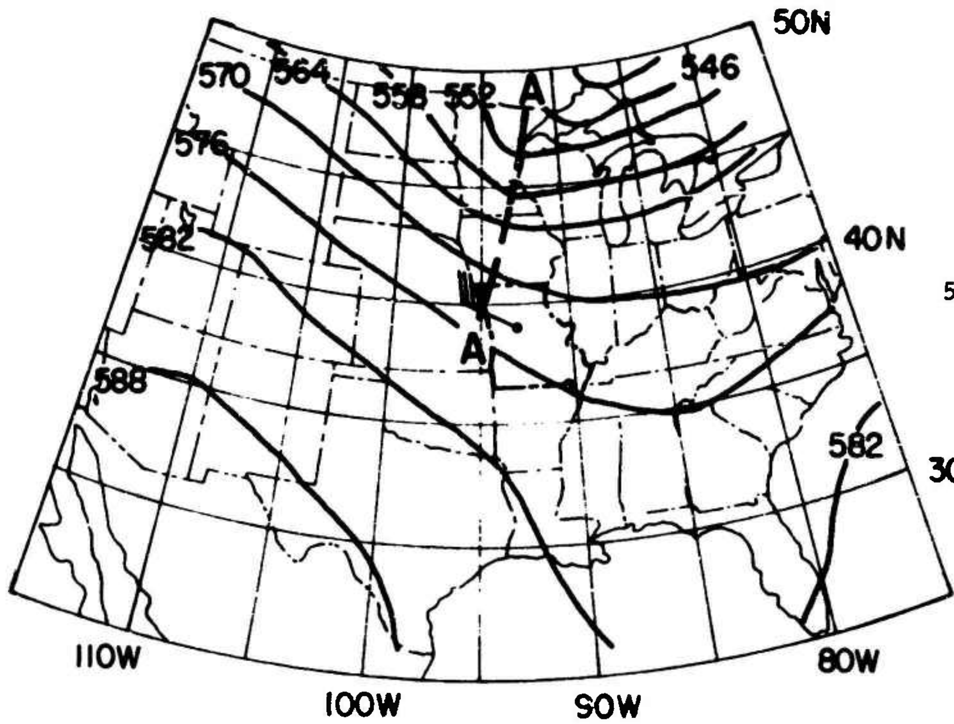


T-8 4531/4530
2150 GMT



T-8 4530/4529
2010 GMT

Fig. 3-38 Pictures from Passes 4530/4529 and 4531/4530 for 2010 and 2150 GMT, 28 October 1964.



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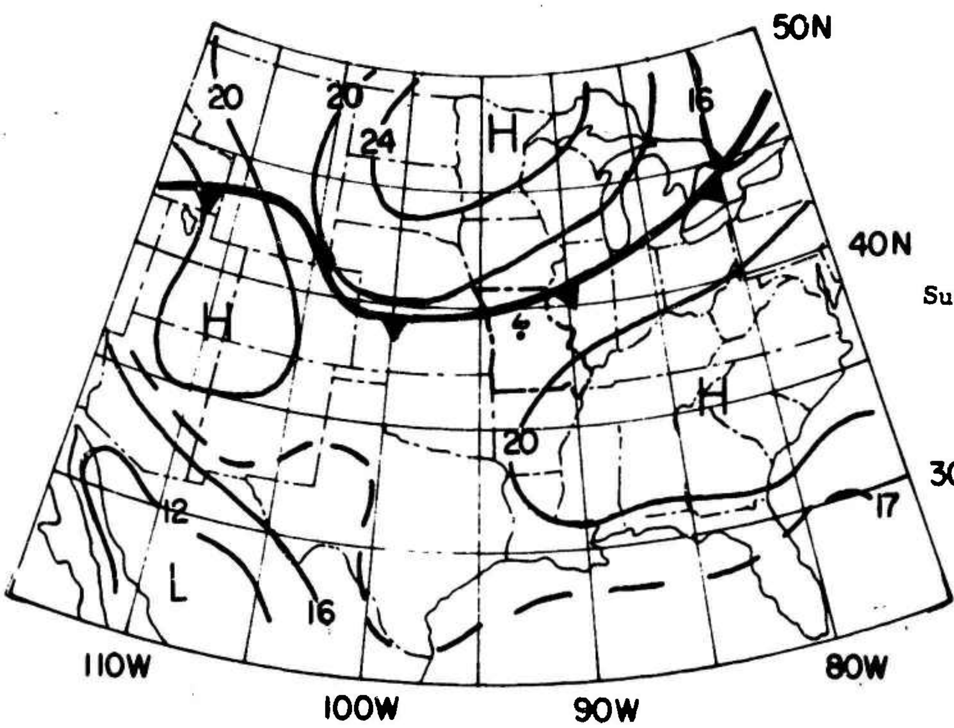


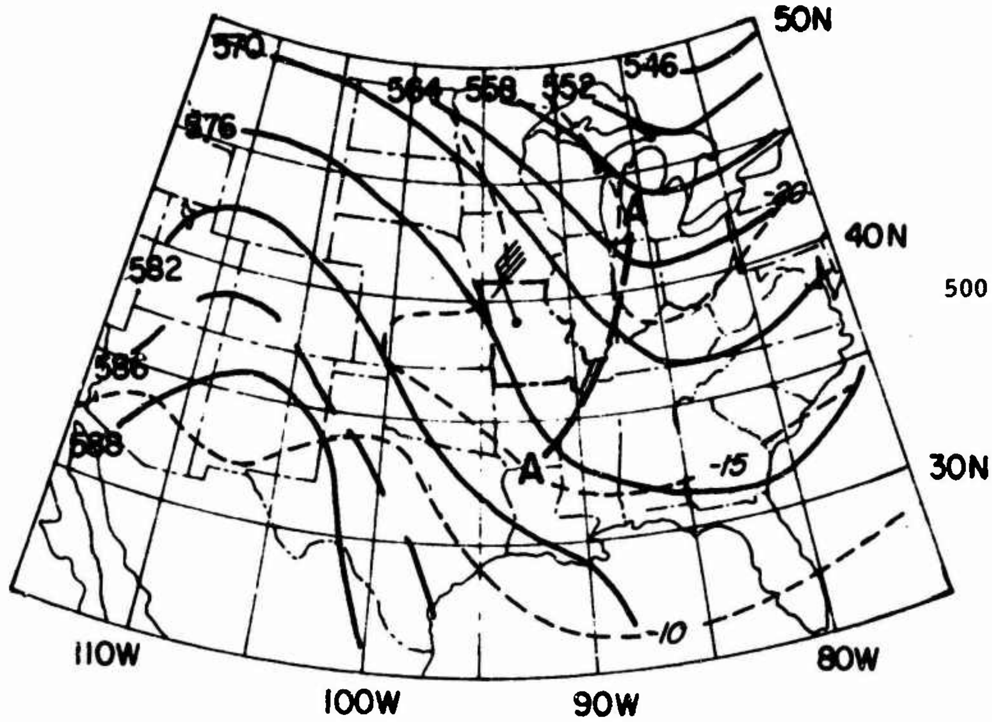
Surface

Fig. 3-39 Surface and 500 mb Charts for 0000 GMT, 29 October 1964.

By 1200 GMT (0600 local), the rapidly moving short wave is passing southeastern Missouri and the winds at Columbia are northerly at 40 knots (Fig. 3-40). The temperature dew point spread has become very large, indicating an extremely low probability of middle cloudiness in the north central Missouri area. By 1200 GMT, the surface front has drifted southward, running northeast-southwest across Missouri, through the southwest corner of Missouri. Scattered clouds are present in the maneuver area, while stations to the east of the front are experiencing overcast conditions with some fog. The rapid movement of the 500 mb trough and the general clearing behind the surface front re indicative of good weather for the next twelve to twenty-four hours. A confirmation of the size of the clear area would have been valuable to the commander at this time. The 1800 GMT surface map places the surface frontal position across the extreme southeastern corner of Missouri. Again, at this time, little or no precipitation was occurring with the front. The satellite pictures taken near 2100 GMT on this day, clearly depicted the large area of clearing skies northwest of the front. Figure 3-40 shows the surface and 500 mb charts for 1200 GMT, 29 October 1964, and Figure 3-41 shows a gridded photograph of this area. The picture, taken near 2100 GMT, shows an isolated white area near 98 west, 37.5 north. It would be nearly impossible to tell, from the satellite photograph alone, whether or not this white area was low-stratus, stratocumulus, or fog. However, a surface report from the vicinity of Dodge City, Kansas indicated complete obscuration with haze and ground fog. Thus, the white patch can be identified as heavy ground fog and the boundaries of this rather large area of fog can be rather precisely determined from the picture. The definition of this boundary would be difficult from a single observation, or even several observations on the ground. Further east and south in the same picture, scattered to broken clouds mark the remnants of the frontal cloud band and indicate its very weak character. In the vicinity of Missouri, only low level cumuliform or stratiform clouds (perhaps fog) are indicated.

During the period 29 October 1964 to 1 November 1964, the deployment of troops and equipment continued. Sites for ALZ's (assault landing zones) to be used by C-130 and other aircraft were being selected and construction by engineer groups begun. Continued good weather was required if these operations were to be completed without delay.

A satellite picture (Fig. 3-41) integrated with conventional data, suggests from the lack of extensive significant clouds that, except for possible nighttime ground fog, good flying weather can be expected for at least the next twelve to twenty-four hours.



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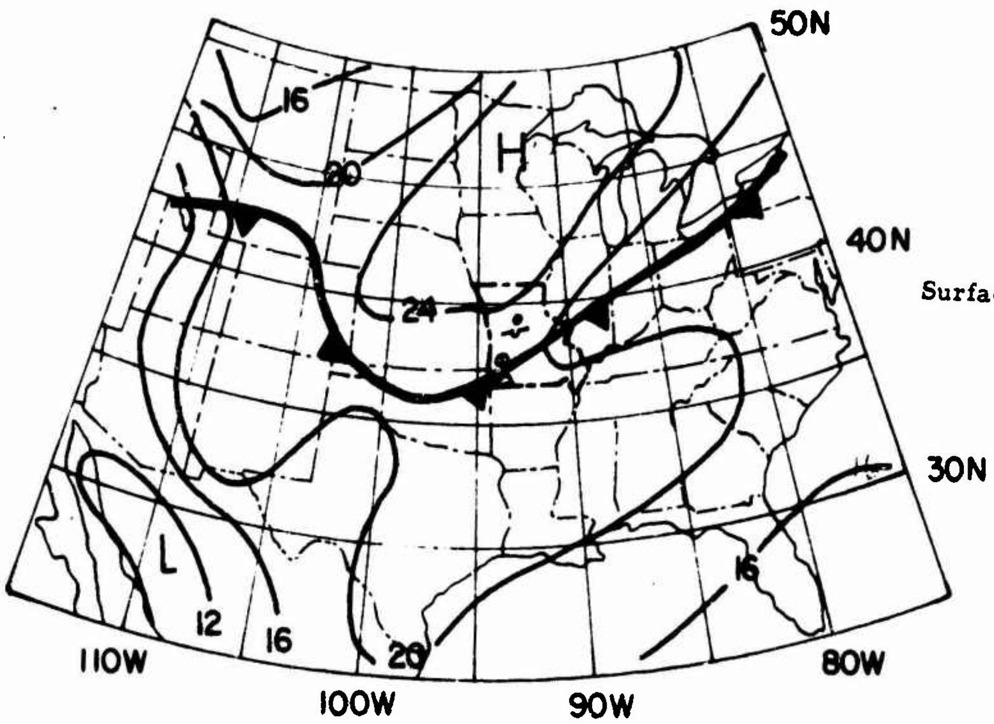


Surface

Fig. 3-40 Surface and 500 mb Charts for 1200 GMT, 29 October 1964.

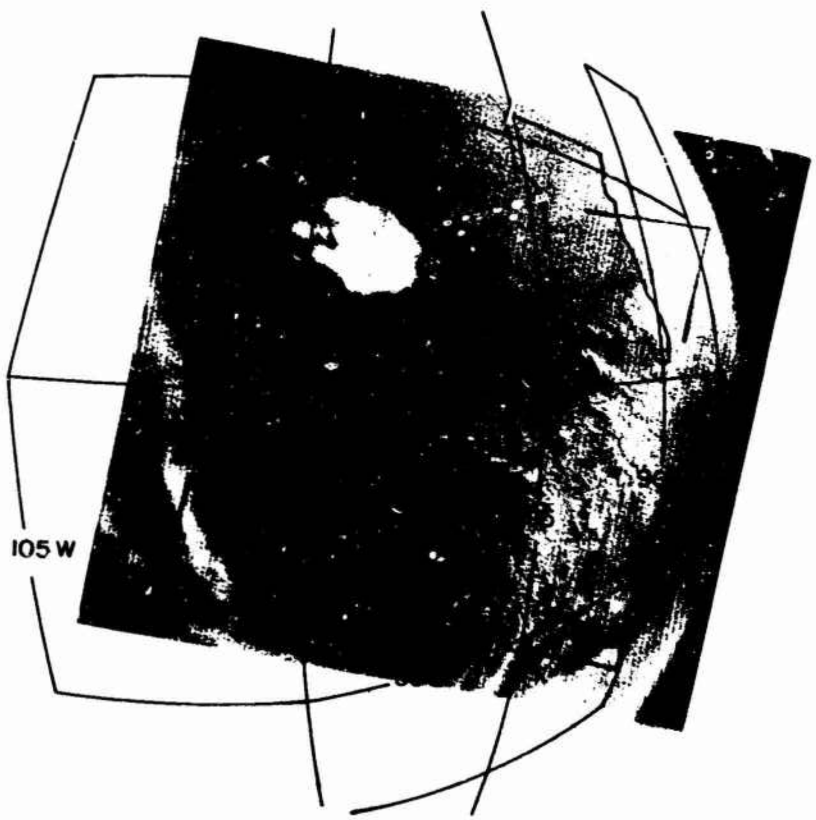


Fig. 3-41 TIROS VIII Photograph. Picture from Pass 4545/4544, 2059 GMT, 29 October 1964.

Fig. 3-42 TIROS VIII Photograph. Picture from Pass 4559/4558, 2009 GMT, 30 October 1964.

3.5.3.5 30 October 1964

Both the 0000 GMT and 1200 GMT 500 mb charts for 30 October 1964 (not shown) indicate a ridge west of Missouri. This ridge moved eastward during the twelve hour period from 0000 to 1200 GMT and some evidence of a decrease in the amplitude of the ridge exists. The satellite picture taken at 2009 GMT (Fig. 3-42) confirms the expected clear skies over central and northwestern Missouri. A weak band of scattered to broken clouds is evident along the Ozark mountain ridge. The scale of this cloudiness and its areal extent would be almost impossible to determine from conventional data. However, the data provided by the picture would be a valuable aid for meteorologists in briefing pilots making flights from the main supply base at Walnut Ridge.

3.5.3.6 31 October 1964

At 0000 GMT, the ridge at 500 mb was over the western boundary of Missouri with nearly clear skies being reported over Missouri, Arkansas, and most of Kansas. By 1200 GMT, the 500 mb wind at Columbia had backed to 260°, indicating the passage of the ridge. Skies were still clear in central Missouri but, with the passage of the ridge, field commanders should be looking for new periods of adverse weather as an upwind trough approached.

A closed center at 500 mb centered over the northwest corner of Nebraska was indicated on the 1200 GMT map. A trough, now over New Mexico, was moving around the main center. A cold front ran from central South Dakota through the Texas panhandle into southeastern New Mexico. No precipitation was occurring along the front and only stations near the front are reporting clouds. The downwind edge of this cloud band associated with the front is difficult to determine from the conventional data and meteorologists at Fort Riley would have found it difficult to closely predict when this cloudiness might affect air operations between Forts Riley and Leonard Wood. In addition, the synoptic situation was potentially a strong weather producer, but the air mass seems to be very dry at both the surface and 500 mb levels.

In the absence of relatively dense conventional data, such as was available in the Missouri area, this type of synoptic situation would present a difficult prediction problem. For example, at 1200 GMT, 31 October 1964 (map not shown) Columbia, Missouri, is reporting a west wind at 500 mb with a 12°C temperature-dew point

spread; Topeka, Kansas (the area from which the supplies and troops were being airlifted) shows a south-southwest wind at 500 mb with an 8°C temperature-dew point spread. If these two rawinsondes were all that were available for upper air data, the forecaster would realize that a ridge is passing the exercise area and that some form of middle tropospheric trough was approaching. At 1200 GMT, dew point depressions were getting smaller toward the trough. The extent of the cloudiness or the severity of weather associated with this approaching trough would not be evident in the data from these two radiosonde stations. The surface data from the combat area shows clear skies while scattered clouds are reported in the vicinity of Fort Riley. (A cold front lies just to the west of Fort Riley through the central part of Kansas.) The meteorologist would probably be overly cautious in this particular situation, since the potential for a weather producing system is evident if only a limited amount of conventional data are available. The addition of the TIROS pictures taken at approximately 2140 GMT (Fig. 3-43) would not only confirm some deductions about the synoptic situation as derived from conventional data, but would also allow better predictions of any possible weather approaching the exercise area in the next several hours.

For example, a forecaster experienced in interpretation of TIROS pictures could quickly recognize the weakness of the cloud band and associate it with a probable surface frontal system, possibly supported by a weak middle tropospheric trough pattern. The following interpretations and deductions could be made based on the data from the two radiosonde stations, limited ground observations, and satellite pictures: (1) a frontal band is approaching the Riley area. Surface conditions in the maneuver area are reported to be: winds southerly, high humidity, and temperatures near 60°F. These conditions will prevail (with normal diurnal changes) until the front passes. Then cooler temperatures, lower humidities, and west to northwest winds will prevail. Thus, prior to the passage of the satellite-located cold front, stable atmospheric conditions would permit useful smoke screens, etc. while after the frontal passages more unstable conditions would probably render smoke screens useless, (2) the cloud band is relatively narrow and shows breaks in the vicinity of 43N. Although the band is nearly overcast along a short portion of its length between 37 and 42N, the clouds do not appear bright, which suggests that the band is principally cumuliform in nature with a high probability that the only middle cloudiness is near 40N-98W (see Fig. 3-43), (3) some scattered cloudiness is still evident near the extreme southwestern corner of Missouri and extends well upwind. Therefore, continued scattered cloudiness in the maneuver area for the next several hours is

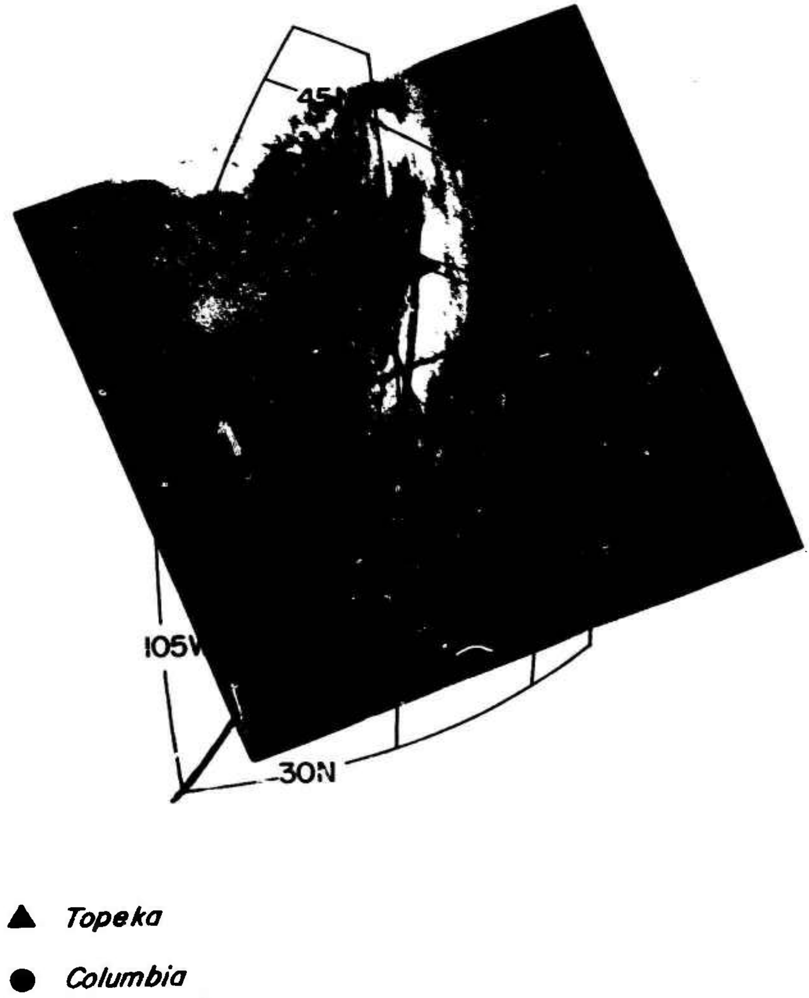


Fig. 3-43 TIROS VIII Photograph. Picture from Pass 7400/7399, 2141 GMT, 31 October 1964. (Frontal Position, 0000 GMT, 1 November 1964).

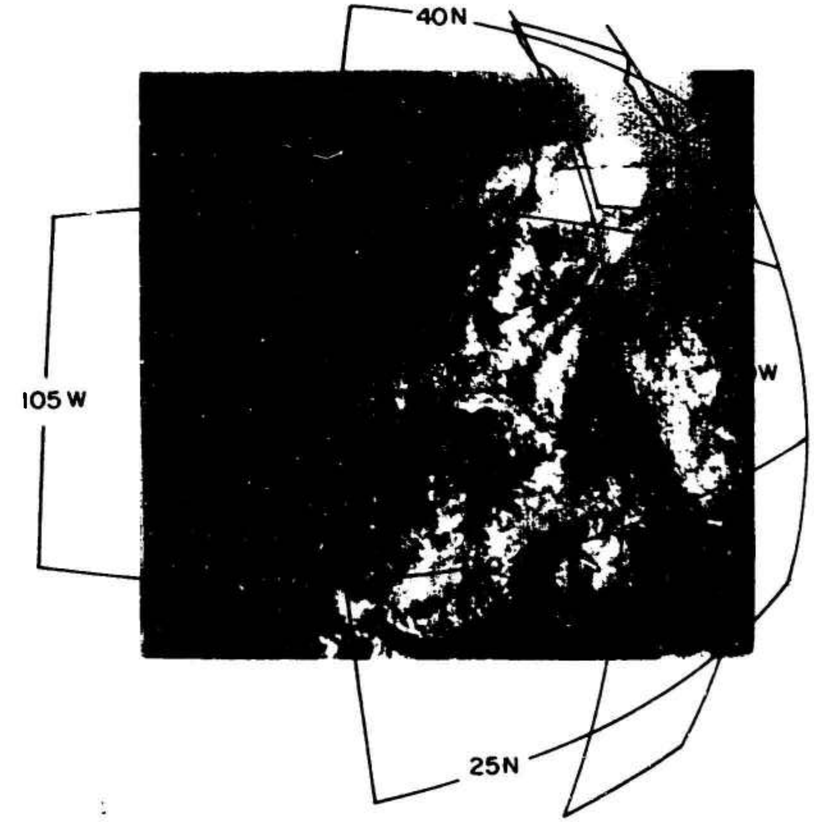


Fig. 3-44 TIROS VIII Photograph. Picture from Pass 4588/4577, 2011 GMT, 1 November 1964.

indicated, and (4) the low level winds from the radiosonde data suggest that this cloud band is moving relatively slowly. This fact, together with the near absence of middle cloudiness, suggests that little precipitation would be expected. Thus, the completion of the deployment of troops and material into the exercise area by mid-day 1 November 1964, should be possible.

3.5.3.7 1 November 1964

To continue this assumed combat environment, the meteorologist's knowledge of conventional data will be assumed to be limited to data from three surface observations, two radiosonde stations and the satellite pictures. The 0000 GMT, 1 November 1964 radiosonde data from the exercise area and Forbes AFB indicate the mid-tropospheric trough is still west of these stations. Saturated conditions were reported at 500 mb over the maneuver area with drier conditions over Forbes AFB. Saturated conditions at the surface, with low level cloudiness, were reported at Forbes while only middle cloudiness was reported over the maneuver area. The probable position of the surface front is shown on the picture in Figure 3-43. (This is confirmed by the conventional surface chart.) Thus, the meteorologist would predict an end to the favorable weather which has allowed troop and equipment movement from Forbes to Fort Leonard Wood.

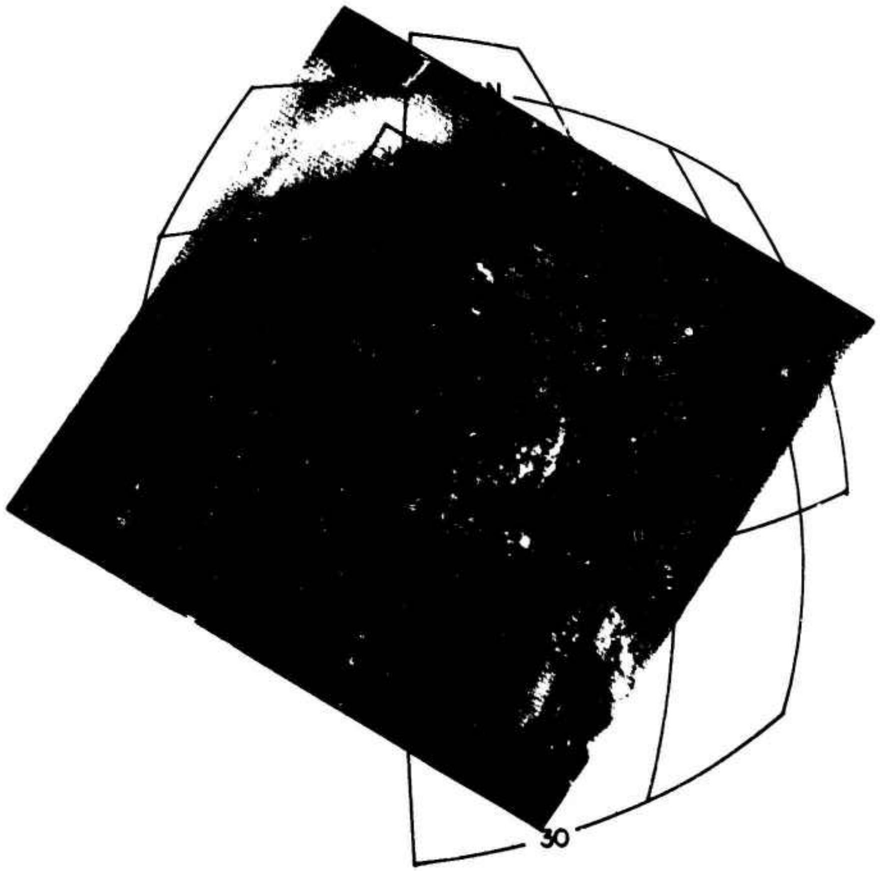
By 1200 GMT (0600 local) scattered clouds were reported at Forbes AFB, while overcast conditions with low clouds have moved east into the maneuver area. The question then becomes one of how long will the adverse weather last and whether sufficient precipitation will occur in the exercise area to hinder construction of ALZ's and interfere with other combat preparations. The TIROS picture taken at 2011 GMT (1411 local) (Fig. 3-44) indicates the extent of cloudiness associated with this synoptic weather situation. In particular, the band across Missouri is very narrow showing a rather bright area over the southwestern corner of Missouri which probably indicates middle and/or high clouds (perhaps associated with convective activity). Again the satellite picture's main advantage is in the clear delineation of the boundaries of the cloud mass and, therefore, the boundaries of the weather situation causing problems to Army field forces. In this case, showery precipitation should be expected in the southwestern portion of Missouri, probably continuing until local sundown. Little or no cloudiness is evident to the west; therefore, once any thunderstorm activity has diminished, little or no weather should be occurring in the maneuver area during the next several hours.

3.5.3.8 2 November 1964

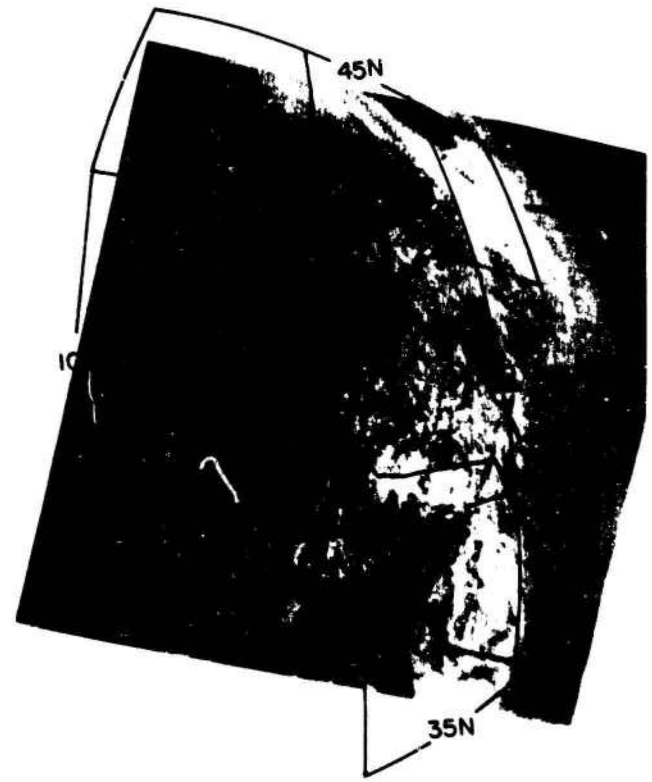
By 0000 GMT, 2 November 1964, the conventional data indicate the trough to be nearly over central Missouri at 500 mb. The skies have cleared in north central Missouri, but middle cloudiness persists at Springfield.

During the period 1-3 November 1964, the second phase of the exercise which was to simulate and prepare for counterinsurgency operations, was underway. JTF Ozark forces were disposed in the initial assembly area with the missions of being prepared for counterinsurgency operations and assisting the friendly country of "Oroland" in external security. Guerilla activity was the principal mission during this phase of the exercise and low level reconnaissance aircraft and close air support were required. The success of such low level air activity depends on relatively good weather (i.e., no low ceilings or poor visibility). In addition, the re-supply of JTF Ozark Forces depended principally on using C-130 aircraft flying into the initial assembly area from a logistics base at Walnut Ridge (100 air miles southeast of Fort Leonard Wood).

The satellite picture taken at 1920 GMT (1320 local) (left of Fig. 3-45) shows an extensive area of low level scattered to broken cloudiness covering the larger part of the State of Missouri and areas immediately south and east. This picture, because of its reasonably good nadir angle, more closely represents the expected APT type picture wherein the area in the center of the picture is viewed by the satellite while looking nearly straight down. This picture can be used to represent an example of the use of the picture data with no conventional data or, at best, a local surface observation. It is interesting to note that a small area in or just south of the Fort Leonard Wood area, over the more hilly terrain, shows somewhat brighter small clouds, indicating the probable buildup of cumulus or cumulus-congestus type clouds. In the right portion of Figure 3-45, another satellite picture of the area taken approximately one hour and forty-five minutes later (having a somewhat higher nadir angle) shows the persistence of the low level cloudiness pattern over central and southern Missouri. The cumulus-congestus type cloudiness mentioned above, now seems to be more widespread and some filling between individual cells seems to indicate the presence of a broad field of smaller scale clouds. Thus, a forecaster-briefer would have direct evidence of such cumuliform buildups to brief the pilots making the re-supply flights from Walnut Ridge to the exercise area. In addition, he could show these pilots direct evidence of the type of weather which will be prevalent in their flying areas. Although such weather does not prohibit



T-8 4602/4601



T-7 7429/7428

Fig. 3-45 Pictures from Passes 4602/4601 (T-8) and 7429/7428 (T-7) 1920 and 2046 GMT, 2 November 1964.

flying, it suggests that proper loading procedures must be strictly adhered to, since a reasonable amount of convective turbulence would be expected with such a cloud pattern. These deductions could be made at forward landing zones and do not depend on good communications or extensive conventional observations.

Although the areas near 35N - 95W appear to have clear areas (or holes), one must be cautioned that at the resolution of TIROS very small scale fair weather cumulus might well be present in these areas and, because of the resolution, would be indicated in a somewhat greyer tone than a more clear area such as perhaps near 98W - 37N.

3.5.3.9 3 November 1964

By 0000 GMT, 3 November 1964, the 500 mb pattern indicated a ridge about to pass central Missouri and an approaching trough to the west. At the surface an old front was indicated slightly east of the 500 mb trough line. Little or no precipitation was indicated along the front. The meteorologist, however, should be concerned with the possibility of the development of a closed system at 500 mb to the west of his position, and the subsequent weather that might affect the maneuver area.

By 1200 GMT (not shown), the 500 mb winds at Columbia and Topeka were approximately 220° 30 knots, but at 500 mb the air mass is relatively dry. The surface front lay across central and western Kansas and into the Texas Panhandle. Although the NMC analysis at 1200 GMT indicated little or no precipitation, some fog was reported at Dodge City, Kansas. An overcast of stratocumulus clouds was reported at Oklahoma City. The satellite pictures (see Fig. 3-46) taken at 1830 GMT (1200 local) show a rather broad band of cloudiness now reaching northwestern Missouri with some broken areas spreading into central Missouri. At this time, the band in southwestern Missouri does not indicate precipitation, except possibly from isolated cumulonimbus which would be in the form of showers. Further north, near the Missouri-Iowa border, and still further north, brighter areas in the band indicate a much higher probability of precipitation. The band near the exercise area is principally made up of low clouds.

The agressor forces (Sioux) were planning an attack on JTF Ozark and presumably would have been interested in a case where inclement weather might have prevented the air superiority of the JTF Ozark forces from being used to advantage. In addition, aircraft reconnaissance would also have been minimized. Such a situation is revealed in the photograph for 3 November 1964 (Fig. 3-46). Based on

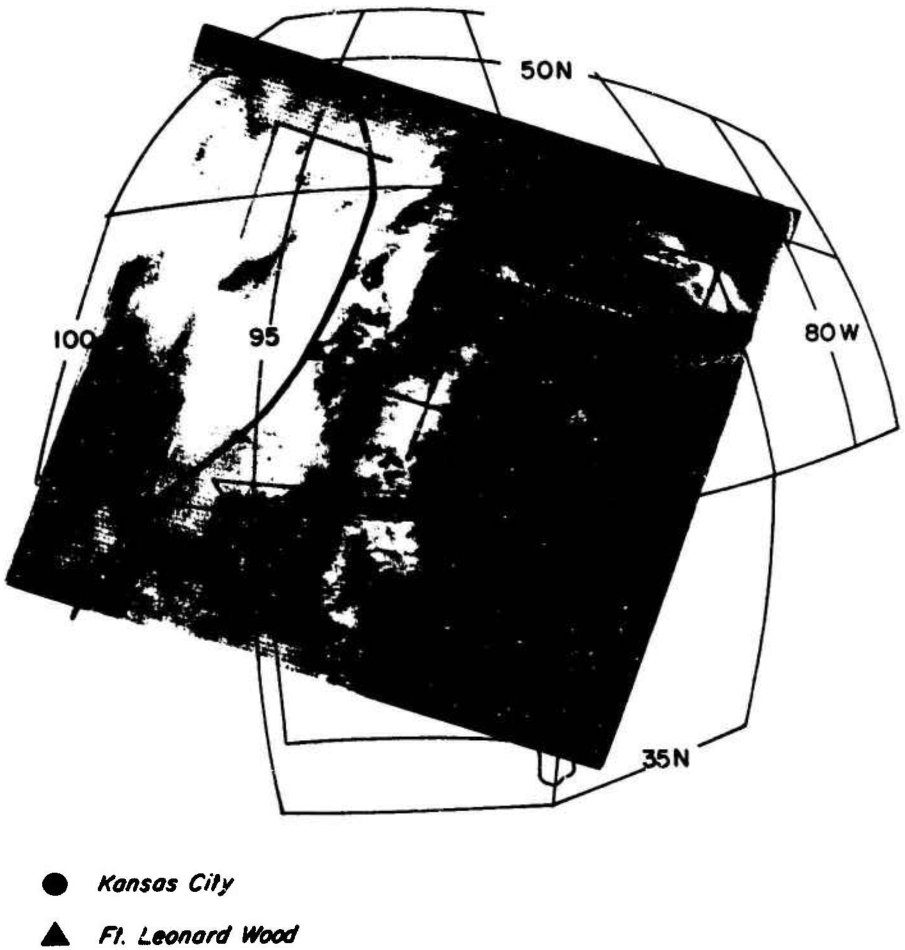


Fig. 3-46 TIROS VIII Photograph. Picture from Pass 4616/4615, 1830 GMT. (Frontal Position at 1800 GMT), 3 November 1964.

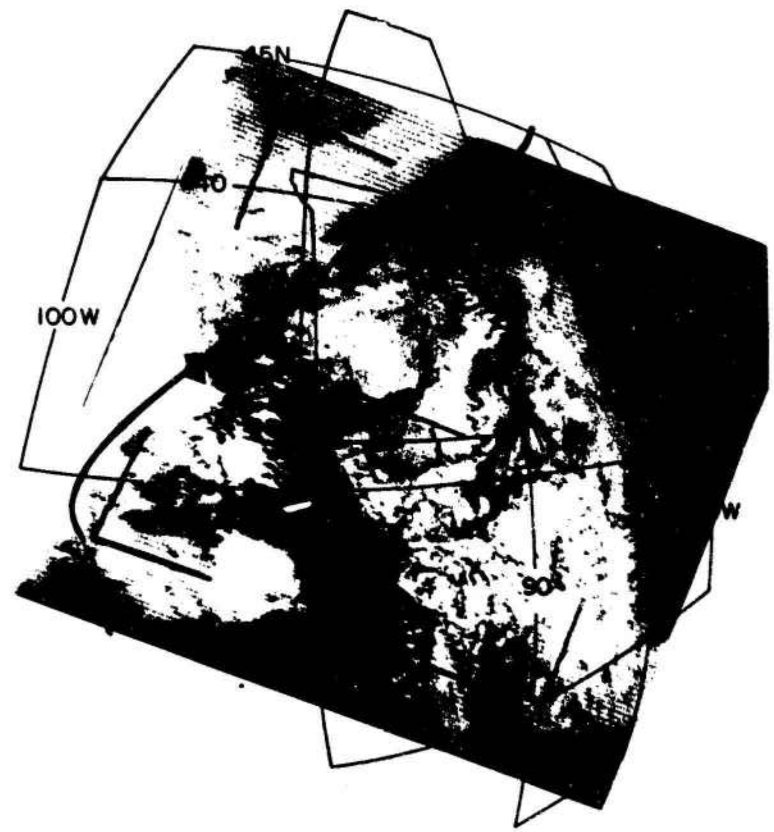


Fig. 3-47 TIROS VII Photograph. Picture from Pass 7461/7456, 1946 GMT (Surface Front Position at 1800 GMT) 4 November 1964.

the integration of limited conventional data and the knowledge of the band shown in this picture, the overspreading of a rather extensive cloud and weather producing system could be expected to begin within the next few hours and to continue for at least the next twenty-four hours.

3.5.3.10 4 November 1964

By 0000 GMT, 4 November 1964, the surface frontal position was indicated to be across the northwest corner of Missouri and broken altocumulus clouds were reported in the exercise area. A short wave in the 500 mb flow is moving around the main closed center, now indicated to be over the Texas Panhandle; the short wave lies generally east-west over Arkansas. The 500 mb dew point depression at Columbia, Missouri at this time is large, indicating relatively dry air at mid-tropospheric levels. However, Topeka has only a 6° dew point depression.

By 1200 GMT, the rapidly moving short wave is now moved north of Missouri and relatively dry air is moving into the Missouri area at mid-tropospheric levels. The surface map for 1200 GMT (not shown) indicates the relatively slow movement of the front. Altocumulus clouds are reported at Little Rock, Arkansas and probably over all of southern Missouri. Little precipitation is reported on the 1200 GMT map. By 1800 GMT (1200 local), the front was indicated to be generally northeast-southwest across central Missouri (see Fig. 3-47) and Columbia was reporting broken to overcast middle cloudiness. Little Rock, to the south, indicated middle cloudiness and haze but no precipitation was reported at this time. There is little on the surface or 500 mb maps to indicate the widespread cloudiness in advance of the front that was shown in the picture in Figure 3-47. As mentioned just above, scattered to broken middle cloudiness is reported at some stations, but at 500 mb the air mass is relatively dry. The TIROS picture (Fig. 3-47) taken at 1946 GMT shows the extensive middle cloudiness associated with the upper level flow pattern, lying generally west of 95°W between 35° and 40°N. The extensive cloudiness over Missouri and to the south is apparently a combination of low level cumulus, some stratus over parts of Missouri (where the pattern appears only gray and relatively flat), and some brighter areas near the center of the picture which are perhaps altocumulus or other middle type cloudiness. The satellite pictures clearly delineate the large extent of this cloudiness and suggest the possibility of some precipitation in central Missouri associated with this convective type cloudiness. Precipitation from the brighter cloud mass further west would certainly be expected in the next several hours.

Of particular importance is the narrow "clear" band indicated on Figure 3-47 by A. This mesoscale clear area results from the gentle downslope motion of the air moving from the south after it passes over the Ozark plateau. Air reconnaissance of this area, as well as supply missions into ALZ's in this area, are possible even though Fort Leonard Wood proper is probably completely "socked in." The detection of this "hole" would be difficult even with a data network as dense as that in the U.S., but was easily detectable in the satellite picture.

3.5.3.11 5 November 1964

The 500 mb chart for 0000 GMT, 5 November 1964, places the closed center over the extreme southeastern corner of New Mexico. Precipitation has broken out over a wide area, including central Missouri, central Arkansas, and parts of Texas. Fog is reported at Oklahoma City, behind the analyzed position of the surface front, which now lies across Missouri in the vicinity of Fort Leonard Wood. The middle cloudiness (reported in Kansas and at Columbia, Missouri) indicates that the weather pattern is associated with a weather producing system at levels other than just the surface.

By 1200 GMT (0600 local), the 500 mb chart indicates the center of the closed system to be nearly stationary. Winds at Columbia, Missouri are from the east-northeast and the air mass at 500 mb is dry. The closed 500 mb center is cut off from the westerlies and is apparently stagnant at this time. At the surface, the front has moved south of Missouri and most of Missouri is indicated to be under the influence of a high pressure area. However, overcast conditions remain at Columbia and drizzle from a stratus deck is falling at Topeka. Stratus clouds are also indicated in central Missouri, probably prohibiting re-supply and close air support missions. With the passage of a cold front, the meteorologist would generally expect improved flying weather. In this case, however, clouds and drizzle persisted after frontal passage. The areal extent and probable persistence of this poor weather would be valuable information for Army commanders, since the weather itself probably limits aircraft reconnaissance. In a combat environment, there would be insufficient conventional data for the meteorologist to make anything but a guess as to the extent of coverage of this cloudiness. In addition, the low stratus obscures the ground observer's view and does not allow him to observe possible higher cloud layers. These higher layers are the ones that usually produce significant amounts of precipitation. The satellite can, however, indicate the general type of cloudiness

over the area in question. The photograph taken by the TIROS satellite at 1832 GMT, 5 November 1964, (Fig. 3-48) indicates clearly the widespread nature of the stratus overcast in the Missouri area. Of specific importance to Army commanders in the Fort Leonard Wood area is the fact that areas to the south, in particular the route from Walnut Ridge to the maneuver area, are relatively cloud free, while areas in the vicinity of Fort Leonard Wood and to the north and northwest (toward Fort Riley) would undoubtedly have low ceilings, perhaps poor visibility, and drizzle from the widespread stratus cloud deck. To the southwest of Missouri, a much more textured appearance to the clouds indicates their more cumuliform nature in this region and that they probably extend to higher levels. This cloudiness has a somewhat hooked pattern and is undoubtedly associated with the closed 500 mb system now centered over the Texas Panhandle. This pattern could be used to locate this system in the absence of conventional data. Precipitation is almost certainly occurring in the area along 35°N between 95° and 99°W. A rectification of this cloud mass (taken from Fig. 3-48) has been superimposed on the NMC surface analysis for 1800 GMT (Fig. 3-49) and the extent of the cloudiness matches well with that reported from the several ground stations. If a combat environment is assumed (i.e., little or no data available from surface observations except in the maneuver area or perhaps from a particular direction; in this case from the vicinity of Fort Riley Kansas) then little could be deduced about the horizontal extent or vertical structure of the cloud cover in the absence of satellite data. The addition of the satellite photograph solves the problem of the horizontal extent of the cloudiness. The picture information, coupled with a surface observation of low stratus, provides the analyst with the boundaries of the very flat appearing stratus cloudiness. The more vertically developed cumuliform cloudiness to the southwest shows where precipitation is likely. Thus, the satellite's principal contributions to the synoptic analysis and prediction procedures, in this case, are the precise determination of cloud boundaries and a determination of cloud type.

3.5.3.12 6 November 1964

During the afternoon of 5 November 1964 (between 1800 GMT, 5 November and 0000 GMT, 6 November), a request was placed by the JTF Ozark forces for an infantry battalion to be airlifted into the area and for a fighter squadron for close air support. These units were to aid Ozark forces in stopping Sioux forces at the Big Piney River and for the preparation of a counter offensive. The satellite picture

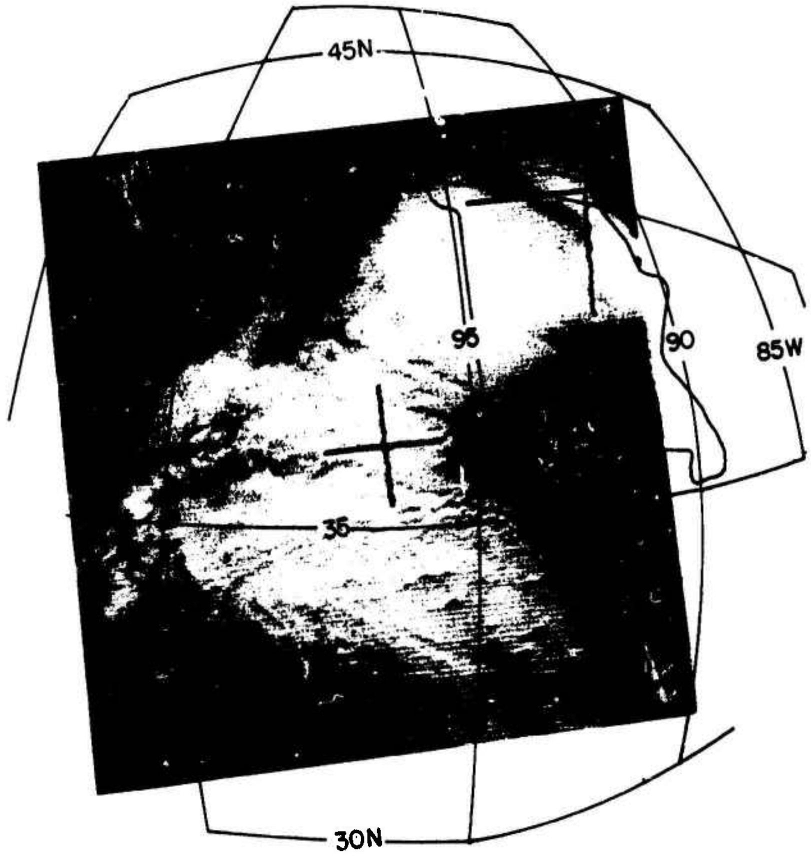


Fig. 3-48 TIROS VIII Photograph. Picture from Pass 4645/4644, 1832 GMT, 5 November 1964.

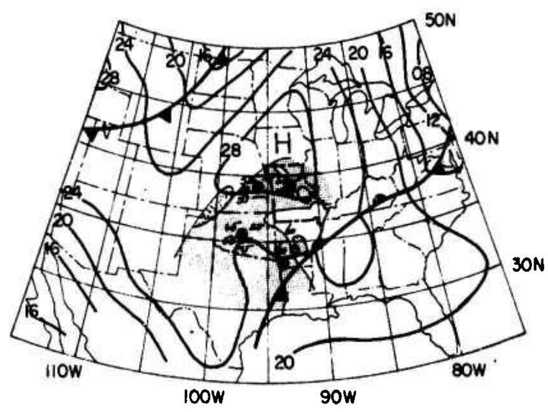


Fig. 3-49 Surface Analysis and Cloud Cover from TIROS Photograph, 1800 GMT, 5 November 1964.

(Fig. 3-48) taken at 1832 GMT indicated the extent of the stratus overcast in and north of the maneuver area. Assuming JTF Ozark air superiority, it might have been a good tactical decision to maneuver the aircraft into the combat area over cover of the extensive stratus clouds to the north. Some element of surprise might then have been possible. The reinforcements (infantry battalion) would probably have had little trouble in reaching the area by the time of the picture. The meteorologist could have given the area commanders a briefing based on the 1830 GMT picture (1230 local) and would have had a relatively high degree of confidence that the pattern would persist for the next few hours. Such confidence would not have been possible from the conventional data alone.

By 0000 GMT, 6 November 1964, the surface map indicated clearing skies as far north as Columbia, Missouri. Extensive cloudiness in the form of low level cumuliform is, however, reported at Topeka, Oklahoma City, and further south. The 500 mb center is still cut off and lies over the Texas - New Mexico border south of Amarillo. By 1200 GMT, the 500 mb center has drifted slightly eastward and lies just southeast of Amarillo, near the Oklahoma border. In the vicinity of Missouri the 500 mb winds have now become mostly southerly, with relatively dry air at the 500 mb level. The surface analysis for 1200 GMT, 6 November 1964, indicates a surface frontal system lying across central Nebraska into eastern Colorado. In advance of this front, stratus and stratocumulus clouds are reported with some ground fog. Columbia, Missouri, to the north of the maneuver area, is still clear while Springfield reports six tenths middle cloudiness and a little fog at the surface. During this period, Ozark commanders were planning a counter offensive against JTF Sioux forces for the following day. Meteorologists would necessarily have been concerned with the possibilities of airlifting both troops and supplies on 7 November 1964, and would therefore have been watching the developing synoptic pattern. In particular, the weather personnel would be looking for any apparent eastward movement of the old cutoff low at 500 mb, which had been stagnant for the previous two to three days. For this situation, the picture provided by the satellite at 1742 GMT, 6 November 1964, when integrated with the 1800 GMT surface analysis, can provide positive clues with regard to the movement of the 500 mb system as well. It can also help in providing information with regard to the exact distribution of cloud cover and the probability of precipitation.

The surface frontal position at 1800 GMT, 6 November 1964, is still northwest of Missouri, lying across central Nebraska (Fig. 3-50). The major cloudiness moving into western Missouri is not associated with the frontal system, but rather

with the eastward progression of the 500 mb system. This cloud band and probable hooked pattern (although it is not clear in the picture shown) are typical of such a 500 mb system. The relatively bright area near the southwest corner of Missouri is principally associated with cloudiness due to vertical motion which in turn results from the advection of vorticity at mid-tropospheric levels. Brighter spots appear imbedded in the cloud mass, indicating some convective activity and the probability of showery precipitation. A line of cumulus congestus and an apparent clear area can be seen lying generally north-south near the maneuver area. The clear area has dimensions approximating 50 nautical miles in width, and perhaps 100 nautical miles in north-south direction. The size of this apparent hole in the cloudiness will probably allow reconnaissance of the maneuver area for the next two hours, after which the eastern edge of the bright cloudiness will move into the maneuver area and showery precipitation will begin. A forward commander might make tactical use of this knowledge by immediately implementing air reconnaissance, since the chances of poor flying weather will increase markedly during the next four to six hours.

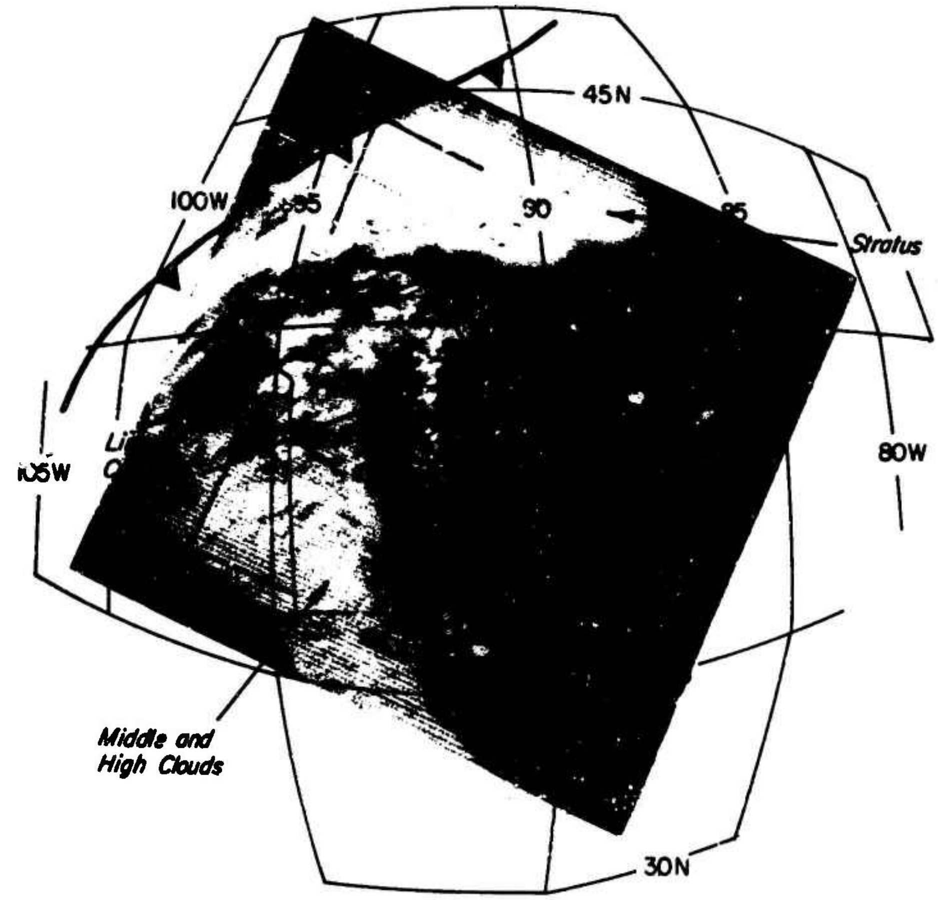
The extensive area of low stratus (relatively flat looking clouds), that was over Missouri twenty-four hours earlier (see Fig. 3-48) has now moved nearly straight northward and the lumpy appearance near the southern edge indicates increased cumuliform development within this stratus cloudiness. The persistence of the shape of this area over the last day is clearly indicated in Figure 3-50.

Figure 3-50 clearly indicates that the flying routes between Walnut Ridge and the maneuver area are free of any adverse weather at the time of the picture and that they will probably continue to be free of major cloudiness for the next few hours. However, as the cloud band moves into central Missouri from the west, a rapid decrease in ceiling and an increase in cloud amount will occur. Thus, commanders should make use of the good flying area to increase supply activity during the next few hours, since poor flying weather, especially at the ALZ's, may prohibit such activity after approximately 0000 GMT, 7 November 1964.

3.5.3.13 7 November 1964

Under the cover of the inclement weather which did cause poor flying conditions, JTF Sioux conducted a surprise attack during the early morning hours of 7 November 1964 (approximately 1200 GMT).

By 0600 GMT showery precipitation had occurred in central and southwestern Missouri. Springfield, for example, indicated 0.15 inches for the twenty-four hours



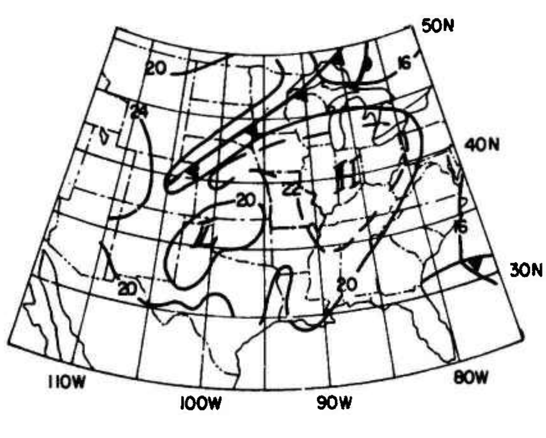
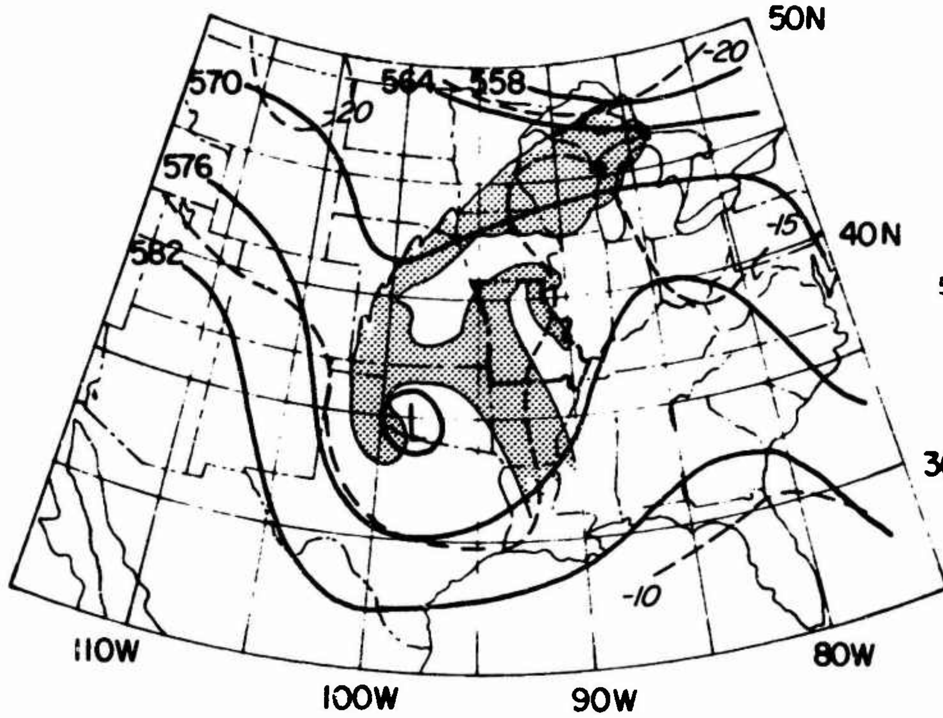
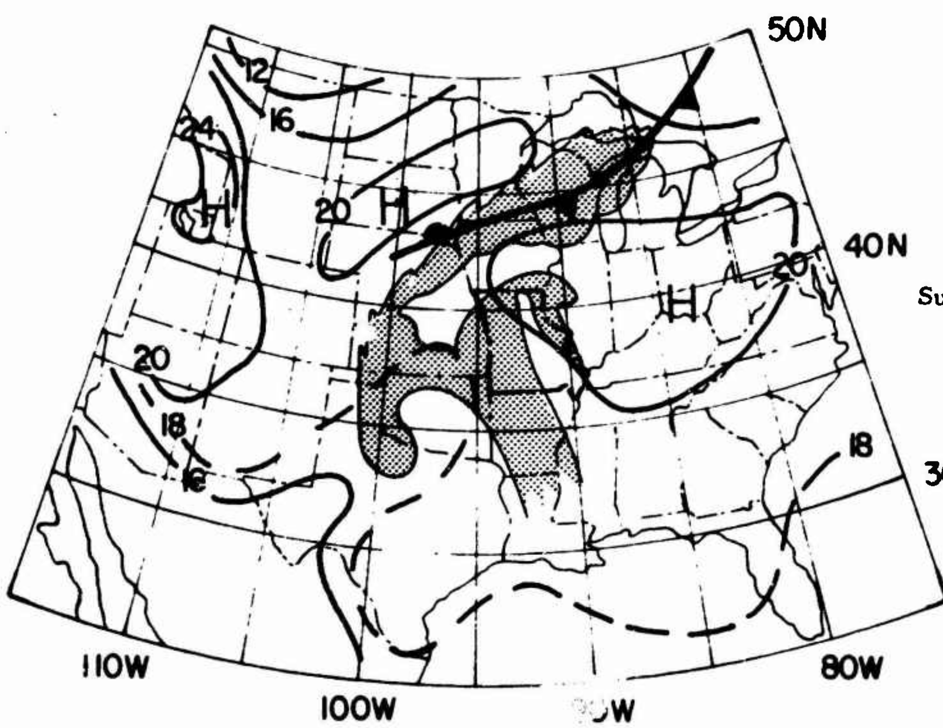


Fig. 3-50 Surface Analysis at 1800 GMT and TIROS VIII Picture from Pass 4659/4658, 1742 GMT, 6 November 1964.

prior to 0600 GMT. The easterly movement of the cloud band mentioned in the discussion of the condition on 6 November 1964, clearly indicated the changes taking place in the 500 mb pattern and, in particular, indicated the probable eastward movement of this previously stagnant system. The 0000 GMT, 7 November 1964, 500 mb chart (Fig. 3-51), indicated the center to be over southwestern Oklahoma and moving eastward at a relatively slow pace. The dew point depression at Columbia, Missouri was only 3^{o}, indicating moisture had now been transported into this area at the 500 mb level. Cloudiness would, therefore, be expected at mid-tropospheric levels and precipitation was likely even though no frontal pattern is indicated on the surface analysis (see Fig. 3-51). By 1200 GMT (near the time of the Sioux surprise attack), the 500 mb system had moved eastward into western Arkansas. Low cloudiness was reported at Springfield and Columbia, as well as to the south near Walnut Ridge. The immediate short term prediction problem was whether or not sufficiently good flying weather would exist to allow an airlift of artillery and infantry into the ALZ nearest the attack zone. A prediction based on the conventional data alone would prove difficult since the boundaries and the vertical extent of the cloudiness would be difficult to determine. The meteorologist would probably be inclined to predict improved flying weather during the next few hours, based on the eastward progression of the 500 mb center. By 1900 GMT (near 1200 local), the satellite picture (Fig. 3-52) provided a confirmation of the synoptic situation and showed the somewhat broken nature of the cloudiness appearing over south central Missouri. This indicated a low probability of precipitation at this time. In addition, the picture indicates no major area of vertical motion which might cause extensive thick cloudiness. An area which appears to be convective cloudiness further north and a sharp band of rather bright cloudiness, running nearly north-south, is in the vicinity of central Kansas and Nebraska. Precipitation may well be occurring with this band. As a confirmation of these deductions, the report states that shortly after this picture was taken, a 105 millimeter artillery battalion was airlifted into the ALZ and deployed against the attacking forces. An infantry battalion was also deployed into the ALZ near the Big Piney River an hour or so earlier. Late in the day, the Sioux forces withdrew because of the success of the airlift operation and the use of the ALZ's. Such an air supported operation must, of course, be re-supplied if it is to be effective. Therefore, the major prediction problem for the following day was whether flying weather would permit the aerial re-supply of the ground forces. During the early morning hours of 7 November 1964, 0.18 inches of rain fell in the maneuver area, accompanied by conditions of low visibility. ALZ's were declared



500 MB



Surface

Fig. 3-51 Surface and 500 mb Charts for 0000 GMT, 7 November 1964 with Cloud Depiction from Satellite Picture for 1742 GMT, 6 November 1964 (Fig. 3-50).

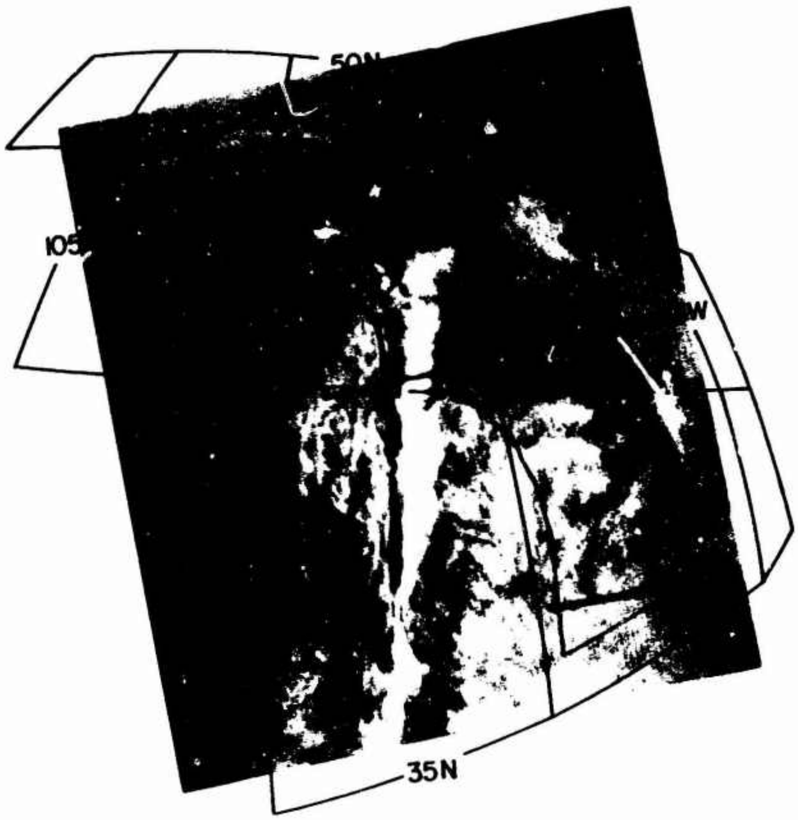


Fig. 3-52 Picture from Pass 7502/7501, 1917 GMT, 7 November 1964.

unoperational due to muddy surface conditions; only twenty-five tons of supplies were lifted over the ALOC (Air Line of Communication), by special aerial delivery means such as low level air drops. It was remarked that had this weather prevailed for a second consecutive day, supply of Ozark forces would have reached and passed the critical stage. Thus, a weather prediction for flying conditions for the following day was of vital concern. The satellite picture (Fig. 3-52) suggests rapid clearing after the system and its associated cloudiness passes east. Therefore, the meteorologist could be relatively assured of such clearing conditions if the system continued to move to the east at the same rate and he could have assured the commander before 2000 GMT (1400 local) that aerial re-supply of the troops appeared possible the next day.

The apparent passage of a cold front (the eastward movement of this cloud band) also allows the meteorologist to predict colder temperatures. In this case, knowledge of the passage of a cold front and the eastward movement of the upper air system (northwesterly flow aloft), both obtainable from the satellite data, strongly suggest cold advection (colder temperatures).

3.5.3.14 8 November 1964

At 0000 GMT, persistent cloudiness was reported over Missouri, but Topeka, to the west, had broken out and reported only scattered middle cloudiness. At 500 mb, the wind at Columbia had backed to the northeast, indicating the center of the 500 mb system was now to the east. The conventional chart shows the center over the extreme southeastern corner of Missouri. The dew point depression at 0000 Z at Columbia was relatively small, confirming the presence of the middle cloudiness shown in the picture (Fig. 3-52). By 1200 GMT (0600 local), the 500 mb wind at Columbia had gone to northerly, indicating the further eastward progression of the 500 mb system. The commander could be assured by this time, based on the eastward progression of this system and by the picture taken at 1917 GMT the previous day, that clearing skies would prevail in the daylight hours on 8 November 1964. The surface charts for 1200 GMT show clear skies at Columbia, Topeka, Omaha, Oklahoma City, and throughout Arkansas. This is another example of how the use of an upper air station located near the combat zone and a limited surface observational network integrated with the satellite pictures, can provide enough data to allow adequate deductions to be made about a critical weather situation. JTF Ozark forces were re-supplied by air and ground for an offensive maneuver which began on

9 November 1964. The expectation of good flying weather allowed the JTF Ozark commanders to plan a counter offensive, using ground, air, and air mobile concepts for the morning of 9 November 1964.

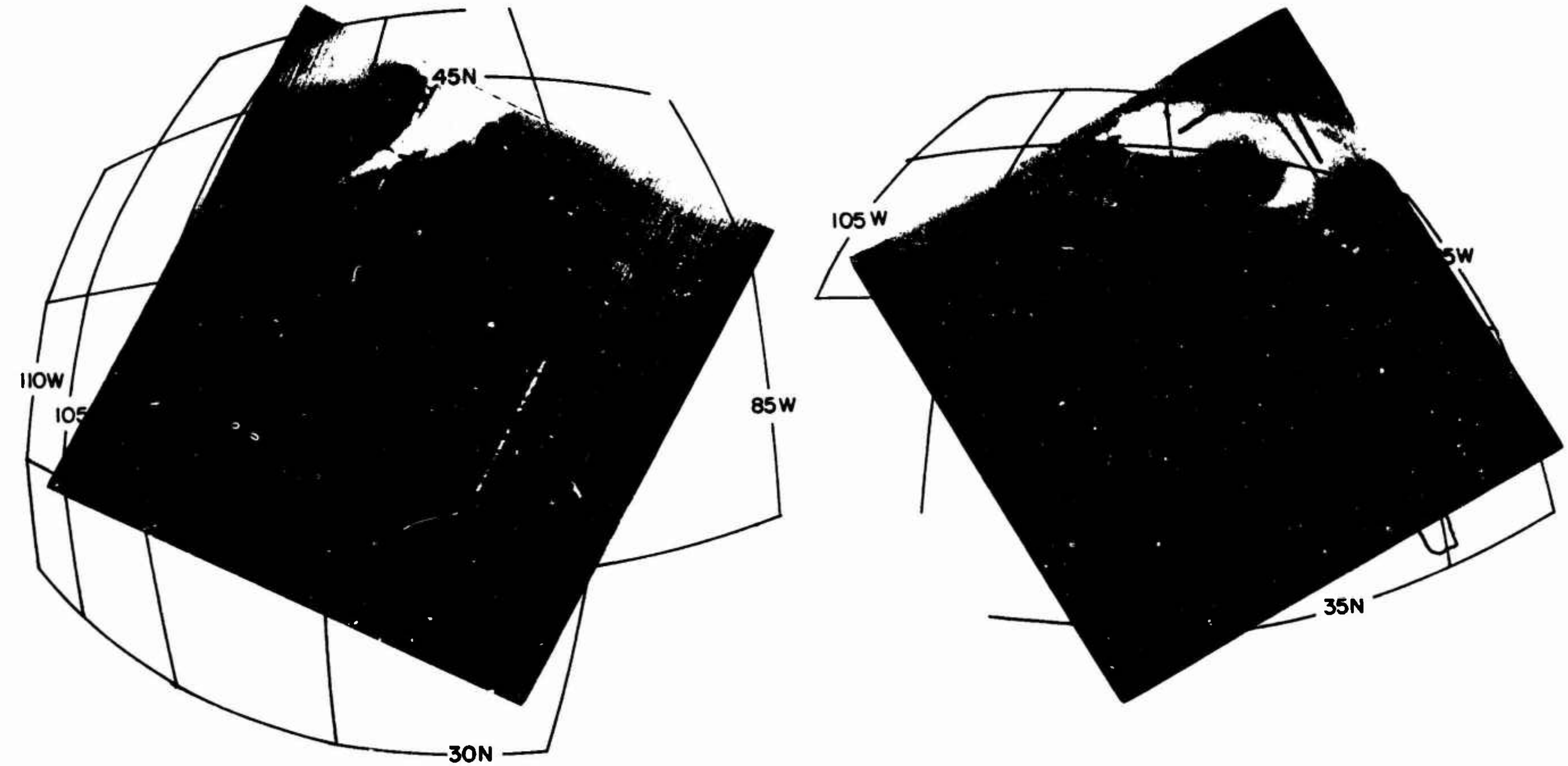
3.5.3.15 9 November 1964

The extremely favorable weather conditions persisted through 9 November 1964. The satellite pictures taken about 1900 GMT, 9 November 1964 (Fig. 3-53), showed nearly clear skies over Missouri and extremely clear skies to the west and southwest for distances in excess of 600 miles. Thus, the meteorologist would have been relatively confident of his prediction of fair skies for the next twelve to twenty-four hours.

There is a further point of interest in these pictures. In the upper picture, taken at 1654 GMT, there is a slight indication of some cloudiness near 95^{o}W, 37.5^{o} to 38^{o}N. The second picture (right side of Fig. 3-53) not only indicates the persistence of this small patch of cumuliform cloudiness, but also suggests a slight increase in area covered by this low level cloudiness, which now stretches into central Missouri. The extent of this cloudiness (which is greater than the resolution of the TIROS system) is clearly evident in these two pictures. Other very small scale cumuliform cloudiness may be present which would not be seen at the resolution of the TIROS cameras.

3.5.3.16 10 November 1964

Continued air attacks in support of the ground attack and the air mobile operation resulted in the aggressor forces being driven back to their staging area on 10 November 1964. The approaching ridge at 500 mb would give weather personnel a strong indication that the cloud free atmosphere would persist for several more hours. By 1200 GMT, 10 November 1964, the 500 mb wind over the combat area had increased to 40 knots from the west, but the atmosphere was still relatively dry. Clear to scattered cloud conditions were indicated in the maneuver area. A fast moving cold front was entering northwestern Missouri, but the frontal clouds appear to be broken rather than overcast. The meteorologist might well have been more wary of a short wave in the mid-tropospheric flow (not shown) now lying along a line across Colorado from the northwest to the southeast. A verification of the position of this short wave and its associated cloudiness would help in predicting for the next several hours.



T-8 4702/4701
1654 GMT

T-7 7531/7530
1821 GMT

Fig. 3-53 Pictures from Passes 4702/4701 and 7531/7530 1654 and 1821 GMT, 9 November 1964.

A satellite picture, taken at 1604 GMT (Fig. 3-54), indicates scattered cloudiness is entering western Missouri and that scattered to broken sky conditions extend westward into Kansas and Colorado. The meteorologist could be relatively confident that the clear skies were to end in the very near future and that scattered to broken cloud conditions would become the weather situation over the entire area in the next several hours. However, continued air support of the ground attack and continued air mobile operations, would certainly be possible for the next several hours (probably until at least 1600 GMT, i.e., through mid-day and perhaps through most of the afternoon of 10 November 1964).

3.5.3.17 Remarks

The goal of this exercise was attained early on 11 November 1964 and the exercise ended. However, several weather critical points were noted in the report of the operation (Reference 5). Although they may not have been specifically discussed in the previous paragraphs, they will be noted here as an indication of other types of weather situations where the satellite might have helped. For example, during the later stages of the operation when clear skies prevailed for thirty-six or more hours, dry weather conditions caused dust to be prevalent at the ALZ's. On at least one occasion, a C-130 type aircraft landing on an ALZ caused dust to fly into the air to a height of approximately 1000 feet. Enemy forces were able to spot such dust conditions and to bring fire to bear on the ALZ. The satellite, by indicating the clear skies for a protracted period, would have helped in suggesting that such dust conditions might be a factor.

Another example not specifically covered is that when the precipitation amounts in the ground strip areas (ALZ's) were such that conditions became muddy, the C-130's were restricted from landing and other systems of delivery were attempted. These air drop systems can be carried out under conditions of good visibility and moderate ceilings, even if the ground is too muddy for landing of the C-130 aircraft. Thus, forecasts of precipitation are critical. Such air drops were used during the period 30-31 October 1964, when muddy conditions prevailed at certain ALZ's.

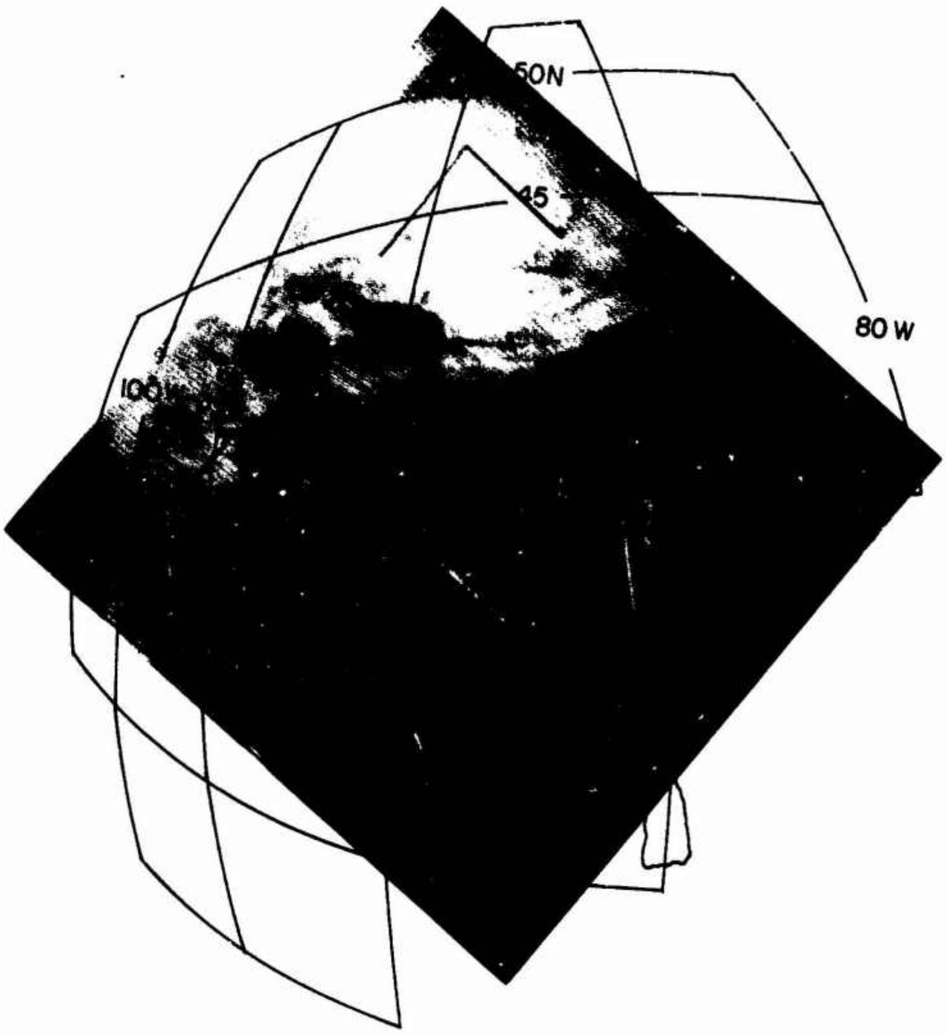


Fig. 3-54 Picture from Pass 4716/4715, 1605 GMT, 10 November 1964.

3.5.3.18 Summary of Results

This case has demonstrated some of the applications of meteorological satellite APT data to the satisfaction of Field Army requirements for meteorological information at the subsynoptic or larger mesoscale. Other potential applications are covered in Sections 2, 3, 4, and 5 of this report and the Operational Guide, also prepared under this contract.

Of particular note is the ability of the satellite data to complement the rather meager conventional data available in a combat environment. For example, this case demonstrated that:

1. The boundaries of cloud areas can usually be precisely defined. Knowledge of these boundaries are directly important to tactical decisions, as well as to weather personnel for predicting maximum and minimum temperatures, probable beginning and ending times of precipitation, etc.

2. Types of cloudiness can be recognized, especially when a limited number of ground reports are available. Some estimates of the vertical development of cloudiness can often be made from the pictures in cases when none could be made from the ground. Predictions of showery rather than continuous precipitation may be possible, based on the observed vertical development.

3. Frontal cloud bands can be recognized as weak or strong, even when good conventional data may prohibit such a differentiation.

4. A positive knowledge of the movement of cloud systems (and hence of the associated synoptic systems) can be obtained from the day-to-day continuity of satellite data.

5. The identification of localized (or mesoscale) areas of cloudy and clear sky conditions was possible (at least for areas larger than the resolution of the camera system).

6. Where two successive passes of the satellite cover a common area, details of the persistence or of short time changes in cloud cover can be recognized and used to advantage.

7. The presence of local cumuliform clouds over the hills and mountains along an ALOC, as depicted in the satellite data, may suggest instability and convective turbulence. Instability and turbulence indicate that loading procedures should be strictly adhered to in order to prevent cargo loss.

8. Knowledge of the terrain, plus satellite indications of a clear area, may allow deductions about low level wind directions, since winds over mountainous terrain often result in local lifting or down slope motions and lead to the generation or destruction of clouds.

9. The satellite data are available to Army personnel from a passive rather than an active, system which provides the advantages of no dependence on communications systems while minimizing the probability of enemy detection.

4. MESOSCALE ANALYSIS AND INTERPRETATION - TASK A

This task has been devoted to the analysis of a category of meteorological phenomena which previously have not received the attention their importance deserved. They are extremely important in the context of this study, because Army tactical operations are pre-eminently concerned with meteorological phenomena in the mesoscale which may range from violent local storms of tornadic character to tactically useful openings in an otherwise uniformly dense cloud cover. Thus, this task covers a large area where research is needed. The results reported below are from studies which only "scratch the surface." Further studies in related areas have been proposed for follow-on research.

4.1 Phase 1 - Severe Weather Situations

4.1.1 Analysis

Severe weather situations of the instability or squall-line type lend themselves particularly well to analysis in the mesoscale, since the thunderstorm complexes which compose the system are themselves mesoscale phenomena. Furthermore, such systems generate some of the most violent forms of local weather and are, therefore, deserving of special study.

Some seventeen severe weather situations occurring in the continental United States were selected for analysis. The basis for case selection was: adequate TIROS coverage, availability of hourly surface weather data, and at least partial coverage by weather radar. Supporting analyses at the 850, 700, and 500 mb levels were also available for all cases.

The analysis procedure for each case was as follows:

1. Determine by means of a grid, the geographical locations of all significant cloud formations in the TIROS photo(s).

2. For the area of interest, perform a series of three mesoscale analyses on maps having a scale of 1:5,000,000--one of these nearest the hour of the TIROS pictures, the others one hour before and one hour after. The principal concern in these analyses has been to depict the mesoscale systems to the fullest extent feasible with the existing reporting networks.

3. Relate the TIROS cloud analyses and the independent mesoscale analyses for the purpose of integrating the two and arriving at a definitive representation of low-level weather phenomena.

4. Incorporate into the composite analysis the available radar data to determine the extent of the precipitation field and estimate (qualitatively) the areas of heaviest precipitation rates, relating these to both the TIROS cloud analyses and the mesoscale surface analyses. The motion of echoes and echo systems were determined from the radar film.

4.1.2 General Discussion of Case Studies

Seventeen cases of convective storm development were analyzed. These occurred during the period from April 1962 through July 1964. The geographical areas ranged from Colorado to Long Island and from Texas to Florida. Eight cases were over the southern plains, four were in the Florida region, three were along the Atlantic coastal plain, one in the northeast and one in the Colorado plains. Although some difficulties were encountered, it was possible to construct hourly mesoscale analyses for most of the cases selected. The difficulties arose for two reasons: the openness of the network of hourly stations, and the problem of data retrieval. The size of meso systems, particularly newly formed ones, is frequently of the same order of magnitude as the spacing between stations. A meso system may form entirely between stations; at most it usually involves one or two stations. However, by using a model based on Fujita et al (Reference 15) (Fig. 4-1), it is still quite feasible to perform a meaningful analysis. Data retrieval proved unexpectedly difficult. Hourly teletype sequences are not preserved intact in any form. Partial sequences in the form of relays are available, but at times many of the stations are missing. These have to be supplied by recourse to WBAN Form 10A.

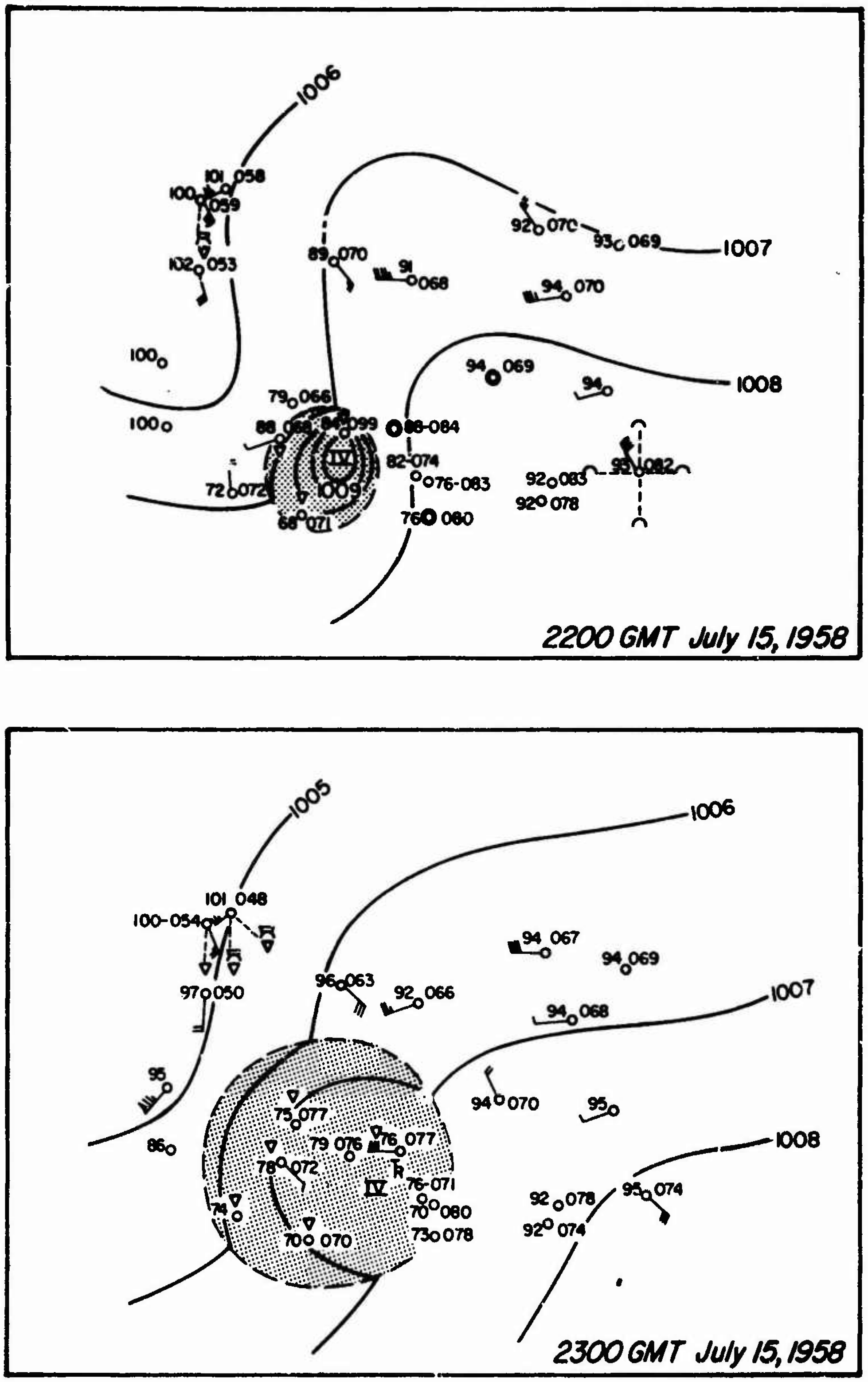


Fig. 4-1 Example of a Mesoscale Analysis (Fujita et al, 1960).

4.1.3 General Results of Case Studies--Findings

The task of mesoscale analysis and interpretation was undertaken realizing that this is a relatively untouched area in satellite meteorology. Thus, while significant results have been obtained, many stones have necessarily been left unturned for the time being.

One principal and anticipated result of this investigation should be emphasized: the satellite pictures are not a guaranteed cure-all for short-range prediction problems. The satellite picture does provide an entirely new approach: it furnishes an immediate and complete appraisal of the state of cloudiness over areas of several hundred miles on a side. This results in the most complete synoptic cloud presentation possible, "synoptic" being used here in its original meaning of a "bird's eye view." It is probably safe to say that given the choice of only a single source of data, synoptic, radar, or satellite picture; the satellite picture, properly interpreted (which implies experience in its use), would provide the best and most complete diagnosis of the current weather and the best point of departure for a short-range prediction. However, like other types of data, the satellite picture is not sufficient unto itself but requires the help of other information for optimum usefulness. As this study demonstrates, satellite data are very readily integrated with radar and mesoscale synoptic data and may be combined with them to produce a very satisfactory and detailed interpretation of mesoscale weather phenomena.

Among the many advantages of satellite data is that of continuous aerial coverage. Even when the coverage by conventional ground data is at a maximum, it is still quite possible for significant, and at times severe, weather to occur between stations and remain, in a sense, "hidden." In these situations, the radar and the satellite pictures are the only definite sources of information on the severity or potential severity of the current weather.

Very short-range predictions are basically an extrapolation. This may be the extrapolation of a motion or of a trend. A minimum requirement is two observations spaced by an interval of time commensurate with the lifetime of the phenomenon being extrapolated. For cyclones, the interval might be three to six hours. For mesoscale convective systems, it is about one hour. It will be some time before the operational satellite program can furnish such frequent observations. Until such a time arrives, dependence must be placed mainly on radar for observations of the motion of severe weather systems. There are usually two motions involved: the motions of individual cells (or more often groupings of cells) and the motions of

the entire system (see AWS TR 184) (Reference 33). The cell or small group motion is closely related to the mean wind between 5000 and 20000 feet, or to the 10000 ft wind which closely approximates this mean. Large convective echoes of fifteen nautical miles or more in diameter, associated with thunderstorm complexes, move in a direction to the right of the upper winds by an angle which varies between 0° and 40°. No reliable indication of direction of advance has been found using the cirrus blowoff or plume which is often seen in these cases. Erickson (Reference 12) has found that, in general, the plume direction indicates the direction of the vertical shear between the lower-tropospheric and upper-tropospheric winds. This direction, however, is frequently at variance with the direction of the mean wind in the lower troposphere. In this study, the plume direction has varied from 60° to the right to 50° to the left of the echo area motion as indicated by the radar. In the absence of radar information, a rawinsonde can furnish assistance in estimating the motion of the storm cells and complexes.

Another obvious use of serial satellite observations would be the identification of changes in intensity of the activity in a storm area and areas of new activity. To be most useful, the interval of observation should be of the order of one or two hours in order to maintain continuity. A single example included in this study reveals that entire clusters of convective cells appear to undergo changes in intensity simultaneously.

One of the most significant findings of this analysis has been the relation of the dimension of the cirrus shield of the convective cloud cluster to the severity of the storm. In an earlier study, Whitney (1963) (Reference 38) found the cloud patterns which produce severe weather to be conspicuous, very bright, and distinctive from other cloudiness. Another finding was that all of the cloud patterns which produced severe local weather were in the 100 to 200 mile (1.7 to 3.3° of latitude) diameter range. Other bright clouds, associated with non-severe thunderstorms in Whitney's study, were less than sixty miles (1° of latitude) in diameter.

In the present study there were seventeen situations for which the TIROS pictures exhibited the distinctive characteristics of conspicuousness and brightness associated with local severe convective storms. A number of the cases analyzed exhibited a rather remarkable agreement between the thunderstorm outflow, meso high as analyzed on the synoptic map, and the size and shape of the cirrus cloud shield which is formed from the combined anvils of several thunderstorms. In fact, it can be concluded that if a cirrus shield of about sixty nautical miles in diameter or over is present, there is a strong likelihood that a mesohigh is associated with it.

In addition, this same feature, i.e., the size of the dense cirrus shield, provided the most reliable indicator of the presence of severe weather. Table 4-1, a contingency table, illustrates this point. In the size group of 1° latitude or less, six cases out of seven were non-severe, i.e., there were neither tornadoes nor severe wind associated with this situation at or near the time of the TIROS picture. The other case was a damaging windstorm. In the largest size group, more than 2.5° of latitude, the three cases were accompanied by one or more tornadoes. In the middle-size group, there were three tornado cases, three were non-severe cases and one case was accompanied by damaging winds. A χ^2 test of this distribution gave a value of $\chi^2 = 6.33$, indicating that the relationship of cirrus shield size to storm severity is significant at the 5% level.

Table 4-1

Relationship of Cirrus Shield Dimension to Storm Severity $\chi^2 = 6.33$

	Cirrus Shield Diameter (°Lat)			
	<1.0 to 1.0	>1.0 to 2.5	>2.5	TOTAL
Severe	1	4	3	8
Non-Severe	6	3	0	9
TOTAL	7	7	3	17

About two thirds of the cases, eleven out of seventeen, showed evidence of a cirrus plume emanating from the bright cirrus shield. Seven of these were associated with severe storms. Of the six cases without plumes, only one had a severe storm. Erickson (1964)(Reference 12) as indicated earlier in this section, had demonstrated that the cirrus plume indicates the presence of a strong shear between the low and upper-tropospheric winds. While there is still controversy regarding the importance of upper level shear in the generation of severe storms, it is recognized, for a number of reasons (Newton 1963) (Reference 23), that severe convective storms show a preference for the jetstream region where strong shear is present. In any case, the presence

of a plume is apparently a good indicator of the presence of a severe storm. However, under conditions of unfavorable picture contrast the plume may not be recognized while the size of the shield is more distinctive.

In some pictures there was evidence that the convection penetrated through the cirrus shield. Severe weather was associated with three out of four cases where such "penetrative convection" was visible at TIROS resolution. There were, however, seven cases of severe weather without evidence of protuberances through the cirrus shield. In these cases, the protuberances may have been of a size so as not to be visible at TIROS resolution. Thus, when protuberances are visible, the probability of severe weather is high. With improved resolution this feature may yield more useful data since smaller penetrating towers may be resolved.

In thirteen out of sixteen cases, prominent mesoscale highs developed; yet severe weather was reported in only six of these cases. On the other hand, in all severe weather situations mesoscale highs were present. This indicates that while the mesohigh may be a by-product of every severe weather situation, it is not a sufficient reason for expecting severe weather since mesoscale highs were present in seven out of ten non-severe thunderstorm situations.

Among the cases, two had meso-high, meso-low couplets. This consists of a mesoscale high with a mesoscale low in close proximity. While the mesoscale high is presumed to result from the cold outflow of the thunderstorm complex, the origin of the mesoscale low has not been satisfactorily explained. When the couplet is present, the severe weather tends to be associated with the mesoscale low according to Fujita et al (Reference 14). This was found to be the case also in two of the instances analyzed here.

4.1.4 The Individual Case Studies

Since it would be redundant to present all seventeen cases, examples have been selected to illustrate the following points of the foregoing discussion:

a) Integration of satellite, radar, and mesoscale analysis (30 April 1962).

b) Agreement or correlation of satellite cloud and mesoscale high.

c) The presence of significant weather when not indicated by conventional data.

d) System motion.

e) Changes in intensity of convective activity.

f) Size of cirrus canopy as indication of severity.

4.1.4.1 Integration of Satellite, Radar, and Mesoscale Data

Satellite Data, TIROS IV, 1457 GMT, 30 April 1962 (Figs. 4-2 and 4-3)

The picture shows one large, bright, cirrus-topped mass, approximately 200 × 260 nautical miles, with less bright cirriform cloud apparently streaming northeastward from the main cloud mass. Within the bright area several rounded, bulging areas can be distinguished (at least in the original picture), suggesting regions of active cumulonimbus development penetrating into the overall cirrus canopy. This case has the largest unbroken cirrus shield of the seventeen cases and this is its most striking feature.

Radar Data, Kansas City WSR-57, 1500 GMT (Fig. 4-4)

At 1500 GMT, there were two lines of echoes, A and B, a third possible line, C, and an area of developing echoes at D. As determined from the radar film, line A advanced eastward at about 33 knots while the average unit speed was 45 knots from 225°. In one hour, by 1600 GMT, line B vanished although line A continued strong. There is no evidence in the TIROS photo of the line structure clearly shown on the radar. The cirrus canopy was apparently dense enough to completely camouflage the line structure, although some of the apparent bulges are located in the vicinity of the radar lines.

In this case, as in any other without visible landmarks, the accuracy of the grid in locating cloud features is open to some question because of uncertainties in some of the satellite orbital and attitude parameters. While the grid error is relatively small, of the order of 1 or 2° latitude, it becomes very significant when applying satellite data to mesoscale situations. Until more accurate techniques become available, the picture grid may be adjusted for a good fit by the use of landmarks if visible in the picture, or otherwise by making the picture fit the locations of the radar echoes which are rather accurately known. Thus in all cases without landmarks shown here, the grid location is a compromise between that given by the computer and the adjustment to fit landmarks or radar echoes. The sketch map in Figure 4-4 is just such a compromise, in which the overall pattern of the TIROS

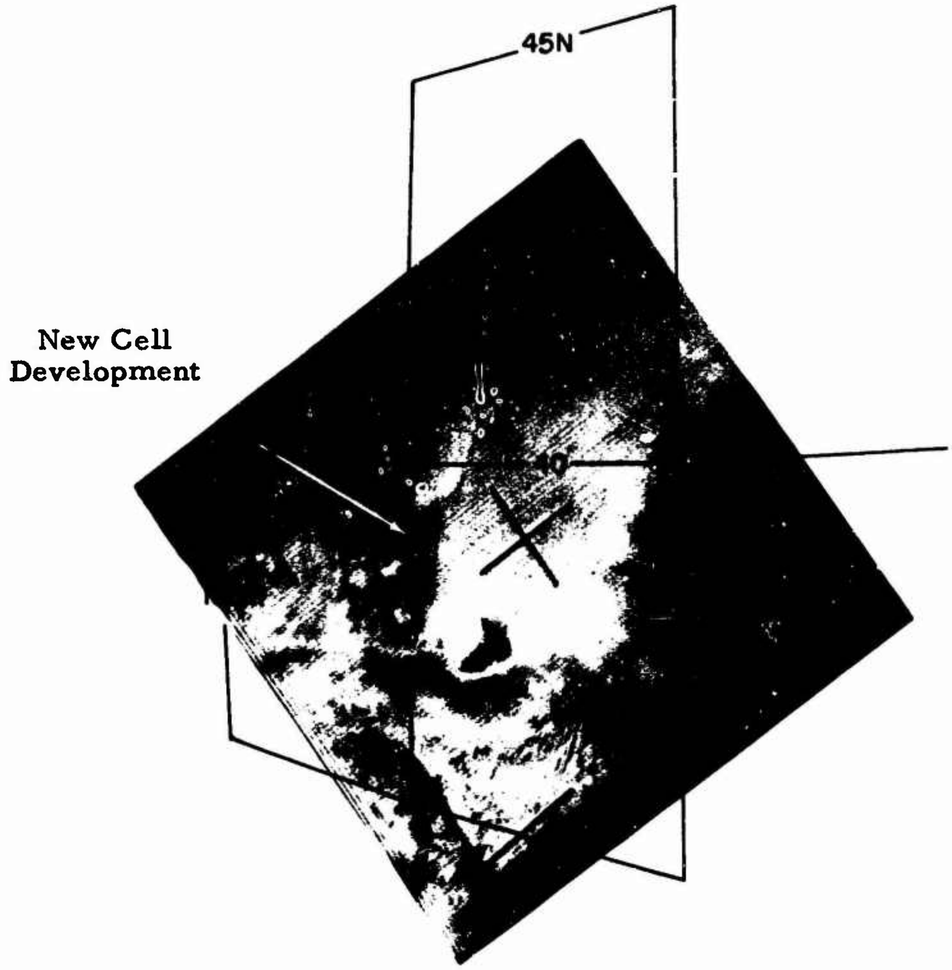


Fig. 4-2 TIROS IV Photograph at 1457 GMT, 30 April 1962, Showing an Unusually Large Unbroken Cirrus Shield about 200 x 260 n. mi. with a Number of Bright "Bulges". Arrow Points to New Cell Development which Acquired Severe Storm Characteristics.

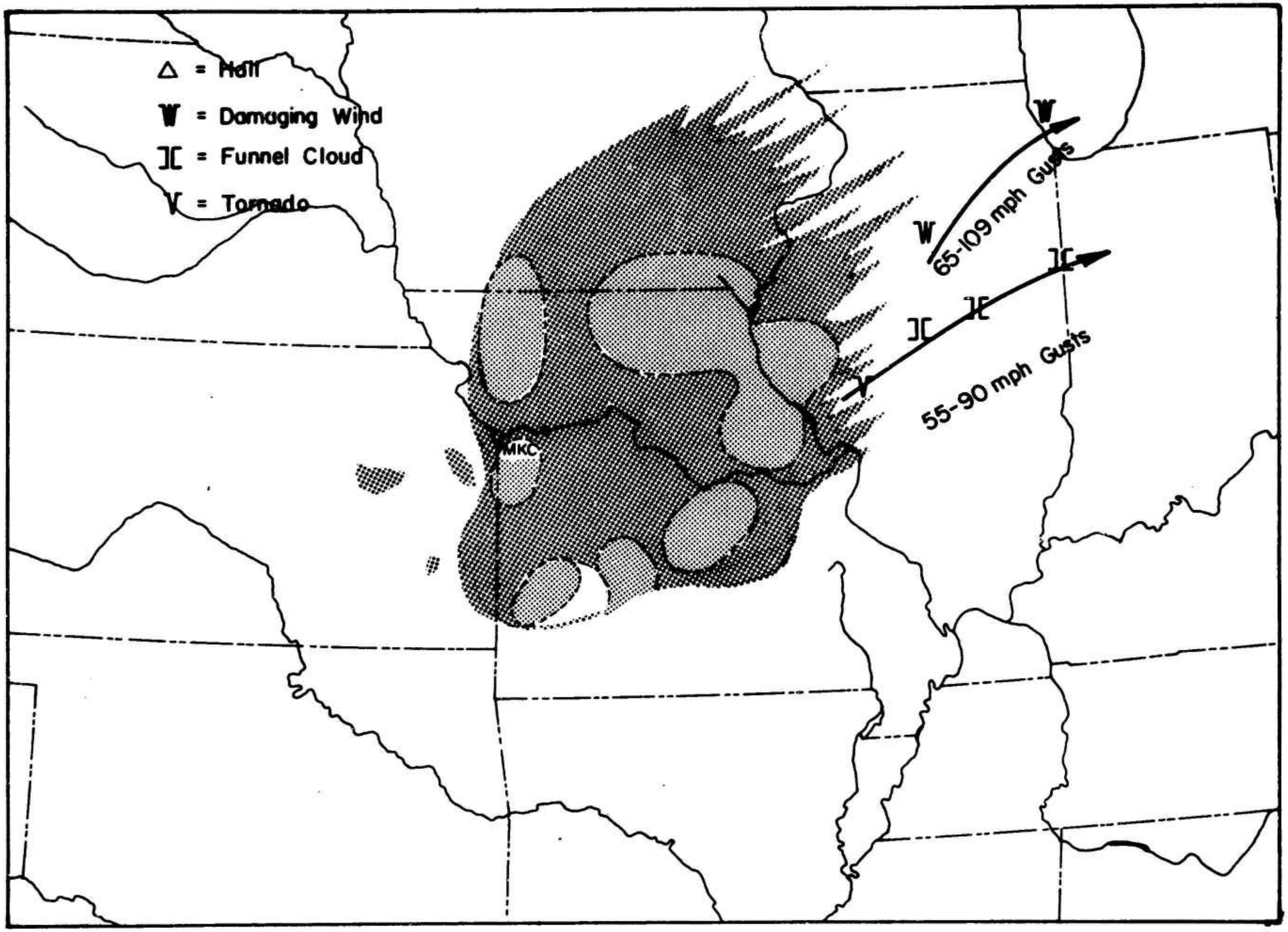


Fig. 4-3 Rectification of Main Cloud Mass from Photograph in Figure 4-2 Showing Areas of Apparent Bulging and Location of Principal Severe Weather Phenomena.

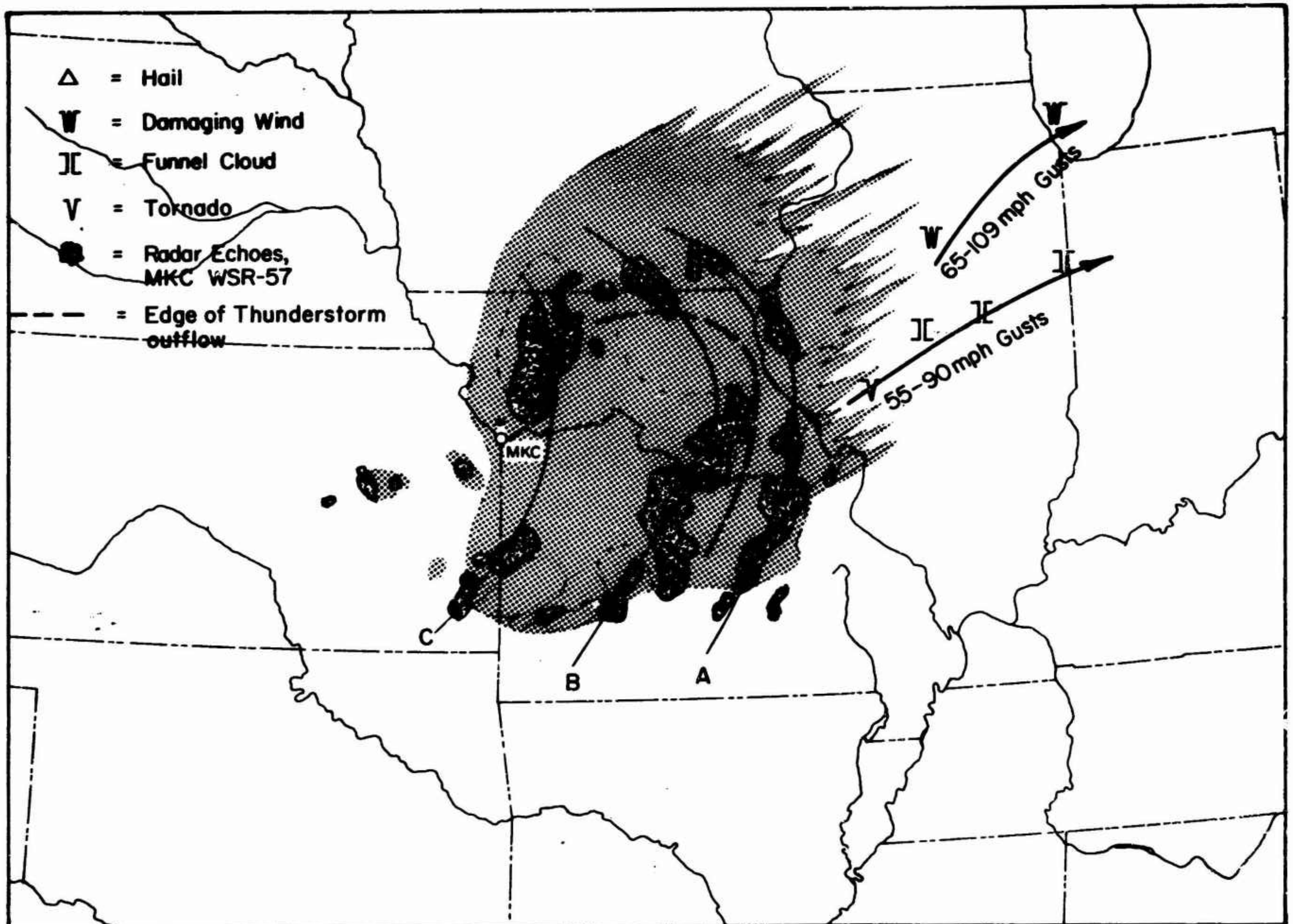


Fig. 4-4 Main Cloud Mass Outline as Seen in Figure 4-3 with Radar Echoes from Kansas City WSR-57 at 1500 GMT.

picture is made to fit the distribution of radar echoes. In this particular case, there are no well defined "anchor points" on which to base the fit, since there are no detached cumulonimbus masses such as are usually present in such situations. In the absence of landmarks and radar data, there is no alternative but to accept the grid as given unless there is serious disagreement with some feature of the surface analysis.

Surface Mesoscale Analysis at 1400, 1500, and 1600 GMT, 30 April 1962 (Figs. 4-5, 4-6, and 4-7)

The large scale synoptic pattern on this day consisted of a frontal trough extending from the western Great Lakes south-southwestward to Mexico and containing two low pressure centers, one southwest of Lake Michigan and a poorly defined center over Mexico. Most of the activity of interest occurred in the cold air in what initially was an area of flat pressure gradient in the trough. This is evident at 1400 GMT (Fig. 4-5) one hour ahead of the TIROS picture when the storm complex was undoubtedly already well developed. Without previous data there is little to suggest that the high pressure cell immediately behind the front is probably a mesoscale high. By the next map, 1500 GMT (Fig. 4-6) the mesoscale analysis reveals a clear-cut meso high centered southwest of Columbia, Missouri, where a rise of 3.3 mb in the past hour and a temperature fall of 8°F are evidence of the origin of the system. In addition, immediately following the high is a mesoscale low (or "wake low," as it is sometimes called) forming a high-low couplet. MKC reports a funnel cloud five miles southwest. By referring to Figure 4-4, it will be seen that the edge of the thunderstorm outflow is just ahead of radar line B, but behind line A and some distance west of the edge of the storm shield. This would indicate that line A is being generated along the cold front. Line B, being located in the meso high or cold outflow area would no longer be in a location favorable for new cell growth and, hence, would be expected to weaken rapidly; indeed by the next hour, it has almost disappeared. Line C, in the rear of the meso high and near the western edge of the storm shield, is in a favorable position for cell growth. The area near MKC is within the area of development of the meso low which has been empirically recognized as favorable for severe storm development. According to the MKC radar, the most significant cell is a relatively new one twenty-one miles west-southwest of the station at 1440 GMT. Although its radar top is observed at only 43,000 feet, this is already a penetration of nearly 3,000 feet above the tropopause. An intensity measurement

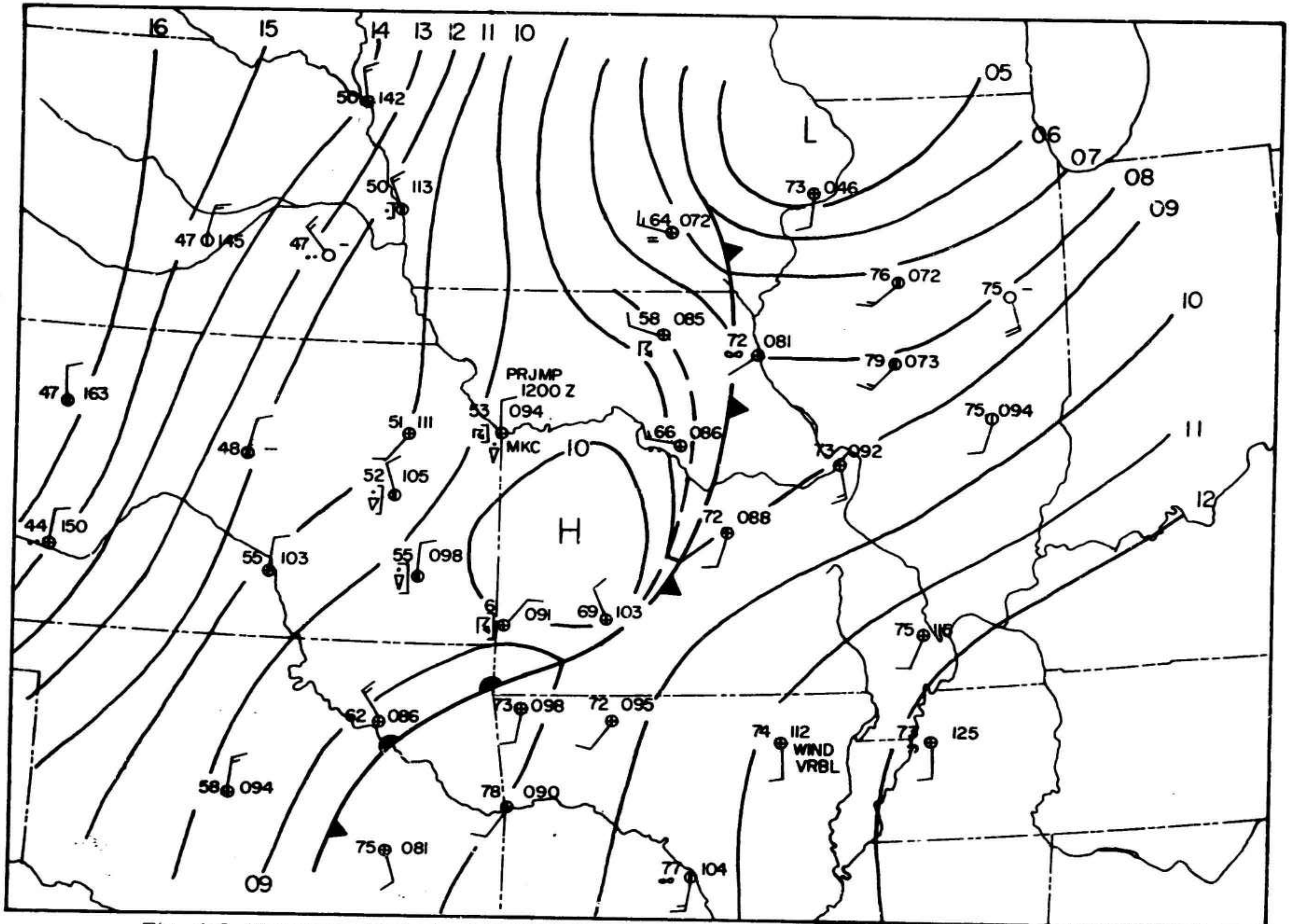


Fig. 4-5 Mesoscale Analysis at 1400 GMT, 30 April 1962. Edge of Thunderstorm Outflow Indicated by Dashed Line.

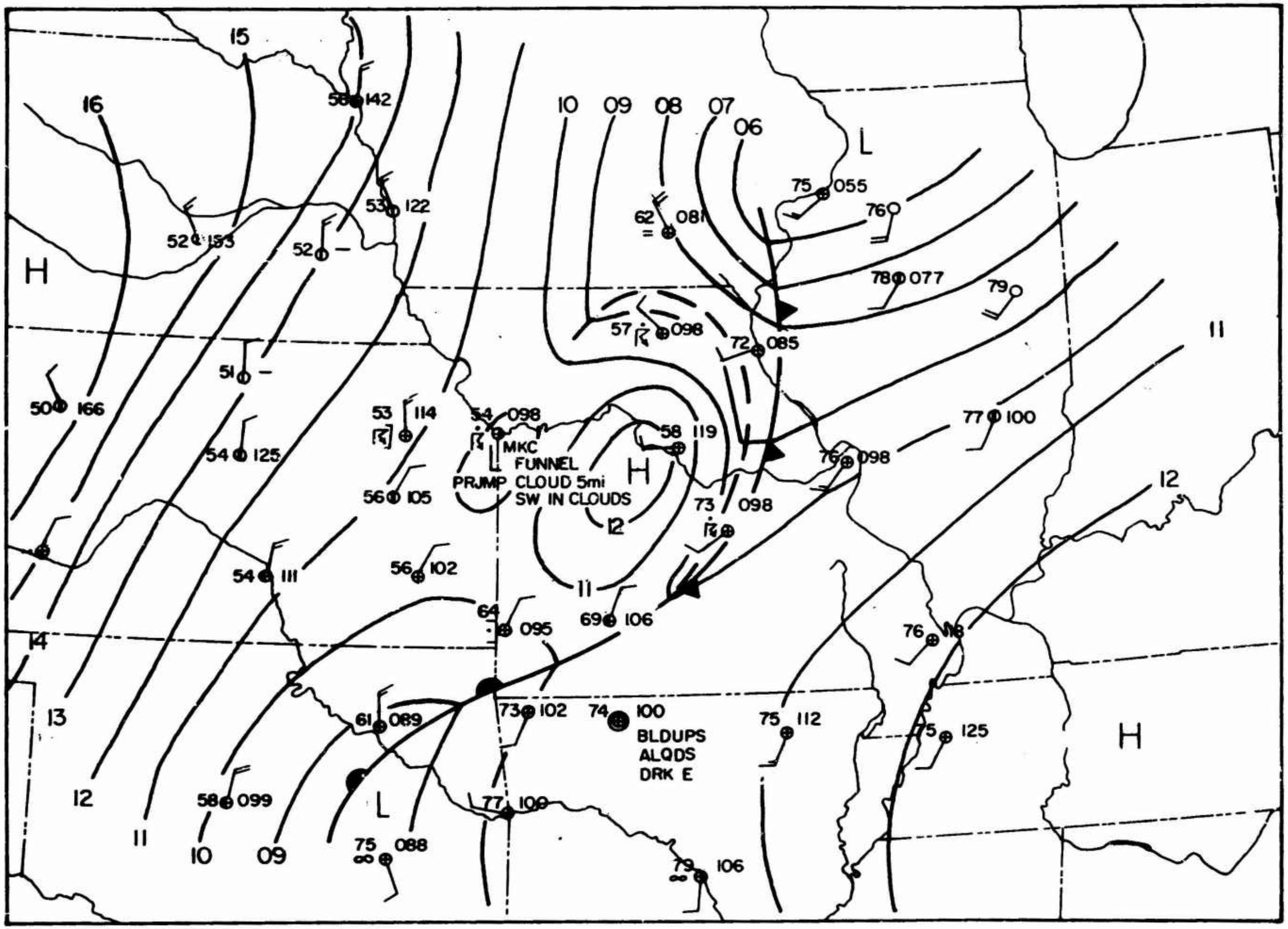


Fig. 4-6 Mesoscale Analysis at 1500 GMT, 30 April 1962.

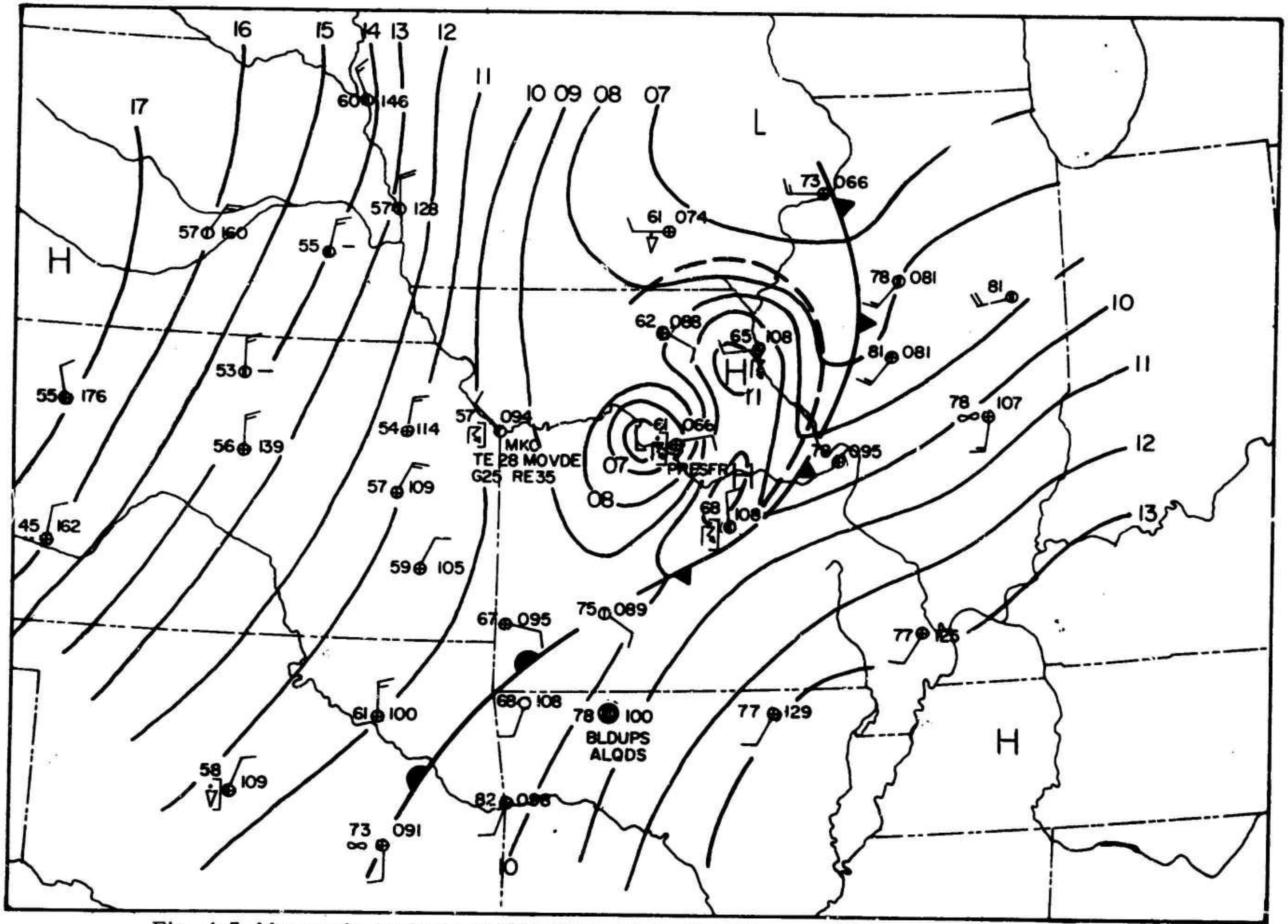


Fig. 4-7 Mesoscale Analysis at 1600 GMT, 30 April 1962. Note Well-Developed High-Low Couplet over Missouri.

indicates a "Z" value of more than 10^6 which, according to Donaldson (1963) (Reference 11), is indicative of the presence of a severe storm. In addition, an RHI observation at 1435 GMT showed some evidence of a funnel. This was later substantiated by visual observation of a funnel cloud. This development occurred in an area immediately to the west of the storm shield, indicated by an arrow in the TIROS picture (Fig. 4-2). In this region there are two cloud masses about twenty-five to thirty miles in diameter which appear rather innocuous in the picture, but which are in a favorable area for rapid development. From 1500 to 1600 GMT (Fig. 4-7) the meso high-low couplet moved about seventy-five nautical miles, the low directly east and the high east-northeast. The former developed a very strong pressure gradient, 5 mb in forty-five nautical miles. The rapid movements produced extreme fluctuations in pressure tendency. At Columbia, Missouri, for example, the pressure rose 3.3 mb between 1400 and 1500 GMT, then fell 5.3 mb between 1500 and 1600 GMT. In spite of the rapid intensification of the meso low, at 1600 GMT the MKC radar reported no unusual activity and none of the cells reported met the criteria for severity. About one hour later, or about the time it would have taken the meso low to reach the Mississippi just above St. Louis, a series of violent storms began and continued following a path approximately northeast through the vicinity of Springfield and Rantoul to the Indiana border and even beyond. At least four funnel clouds were reported, one definite tornado and wind gusts to 90 mph. A similar but shorter severe storm swath further north ended in the outskirts of Chicago. This one had wind gusts as high as 109 mph.

Summary

In this case, the magnitude of the cirrus shield in the satellite picture focuses attention upon the storm area as a potential source of severe weather. This is, of course, borne out by the facts. However, from the satellite picture alone, there is little or no indication as to where the severe weather is to be expected. In this case, the severe weather developed from new thunderstorms which formed in the wake of the original storm area, in the cold air well behind the cold front, and were associated with a "wake low" immediately following a meso high. The satellite data did little more than "flag" this as a severe weather situation. Clues as to the location of the severe weather were furnished by the radar and the mesoscale analysis.

4.1.4.2 Correlation of Satellite Cloud Shield and Mesoscale High and Indicators of Significant Weather When not Indicated by Conventional Data

Satellite Data, TIROS VII, 1900 GMT, 20 April 1964 (Figs 4-8 and 4-9)

The outstanding feature of this picture is the bright cloud mass about 2.5° latitude (ninety nautical miles) in diameter, centered at 39°N and 95°W. Other features are the line of bright cumuliform cloudiness trailing southwestward from the large cloud mass. This was one of the few cases of severe weather observed by satellite in which the line formation was evident in the satellite picture. A second cloud mass, smaller than the first, is found to the southeast of the first at 37°N and 92°W. The cirrus shield of the larger cloud mass is unbroken with only a slight suggestion of a bulge near 38°N and 94°W. Of interest also is a thin line of clouds, probably cumulus, along the southwestern edge of the shield.

Radar Data, Wichita WSR-57, 1900 GMT (Fig. 4-9)

This situation was under surveillance by both the Kansas City and Wichita WSR-57 radars. The latter, using a range of two hundred and fifty nautical miles, had the entire system, as seen in the TIROS picture, within range. The radar depiction was that of a right-angled line: a short section A-B, about one hundred nautical miles long, oriented northwest-southeast; and a longer section B-C, about two hundred and fifty nautical miles long, oriented northeast-southwest.

The speed of the individual cells averaged forty-seven knots from 230° in response to a southwesterly flow of fifty knots or more at the 500 mb level. Line A-B, being oriented nearly perpendicular to the upper level wind, advanced at about forty knots while line B-C, whose cells were aligned more nearly parallel to the wind, advanced in a direction normal to itself at no more than twenty knots. The radar logs from Kansas City, Wichita, and Oklahoma City have no records of echo intensity. None of the echoes are classified as stronger than moderate except one east-northeast of Wichita which was rated strong with tops to 48,000 feet (Fig. 4-9).

In this case, as in the previous one, no landmarks are visible. The geographical grid was therefore adjusted to fit the radar echoes. Adjustment was of the order of 0.5° of latitude.

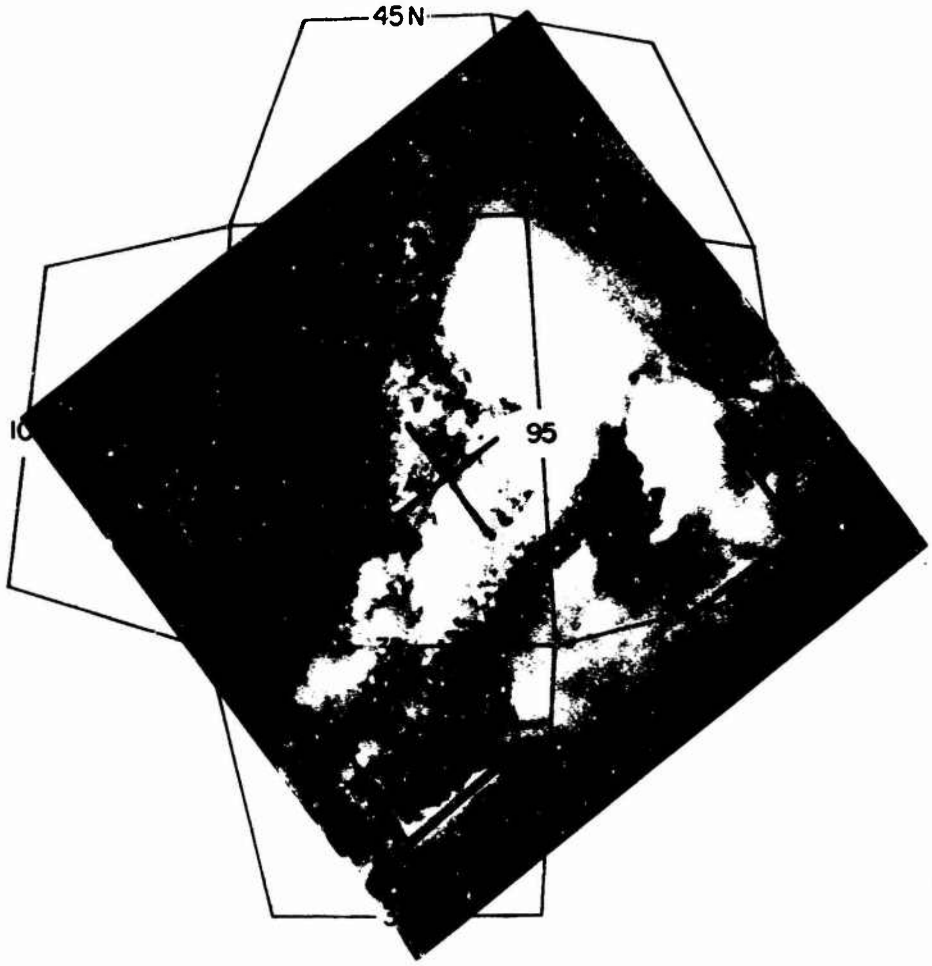


Fig. 4-8 TIROS VII Photograph of Large Bright Cloud Mass about 90 Miles in Diameter with Line of Cumuliform Cloudiness Southwestward.

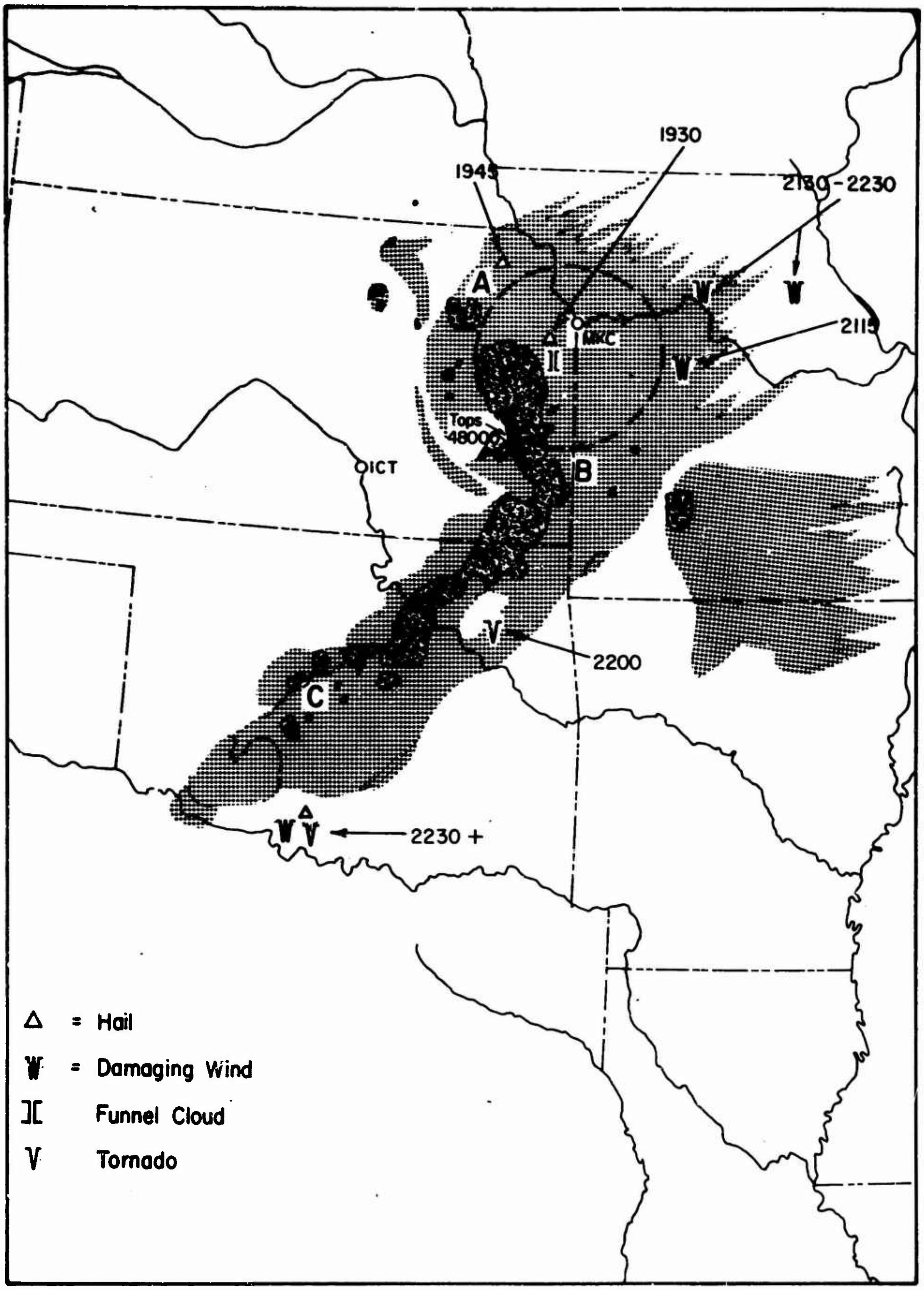


Fig. 4-9 Map of Principal Cloud Features from Figure 4-8 with Radar Echoes from Wichita, Kansas, Superimposed. Symbols Indicate Locations of Severe Weather Phenomena. Times of Occurrence in GMT.

The sketch map (Fig. 4-9) is a composite of the satellite and radar depictions. It shows, among other things, that only a fraction of the cloud mass is producing precipitation (Nagle and Blackmer, Reference 21). It also indicates that, in a moving line such as this, the precipitation tends to be found nearer the windward or upstream edge of the cloud mass. In the northern semi-circular cloud mass, the cirrus shield apparently has a shelf-like extension into the wind. This is eroded by the wind producing a sharp, semi-circular edge. In the opposite direction, the shield trails some one hundred and twenty nautical miles in the direction of the wind leaving a more irregular edge. This same effect, but on a smaller scale, can be seen in the smaller cloud mass to the southeast.

Surface Mesoscale Analysis at 1800, 1900, and 2000 GMT, 20 April 1964 (Figs. 4-10, 4-11, and 4-12)

The large scale synoptic pattern consisted of a cyclone centered near the Oklahoma Panhandle, with a trough southwestward. This system was supported by a vigorous short wave trough near the Rockies, preceded by a strong southwesterly flow. It is beneath this southwesterly flow that the activity depicted by satellite and radar occurred.

The 1800 GMT synoptic analysis (Fig. 4-10) indicates only a simple warm front-cold front structure. Even on the mesoscale analysis for the same hour, there is no suggestion of any extensive array of thunderstorms with only two stations reporting thunderstorm activity. There is no evidence at this hour of any mesoscale structures. On the mesoscale analysis for 1900 GMT (Fig. 4-11) there is some evidence of the development of a meso high in the general vicinity of Kansas City (based mainly on the slightly anomalous pressure field and the hourly pressure changes). By the next hour, 2000 GMT (Fig. 4-12), the meso high is well-defined and centered near Kansas City which experienced a pressure rise of 1.5 mb during the previous hour. There is still nothing in the analysis itself (such as a trough) to suggest the existence of thunderstorm line B-C, although this can be inferred from the remarks in the individual reports.

By referring to the sketch map (Fig. 4-9), it will be seen that the boundary of the meso high is concentric with, but less extensive than, the cirrus storm shield. This agreement is not simply a coincidence. In most of the cases studied which had large and semi-circular cirrus shields, a mesoscale high is found at the ground in such a position as to suggest a direct relationship between the two phenomena.

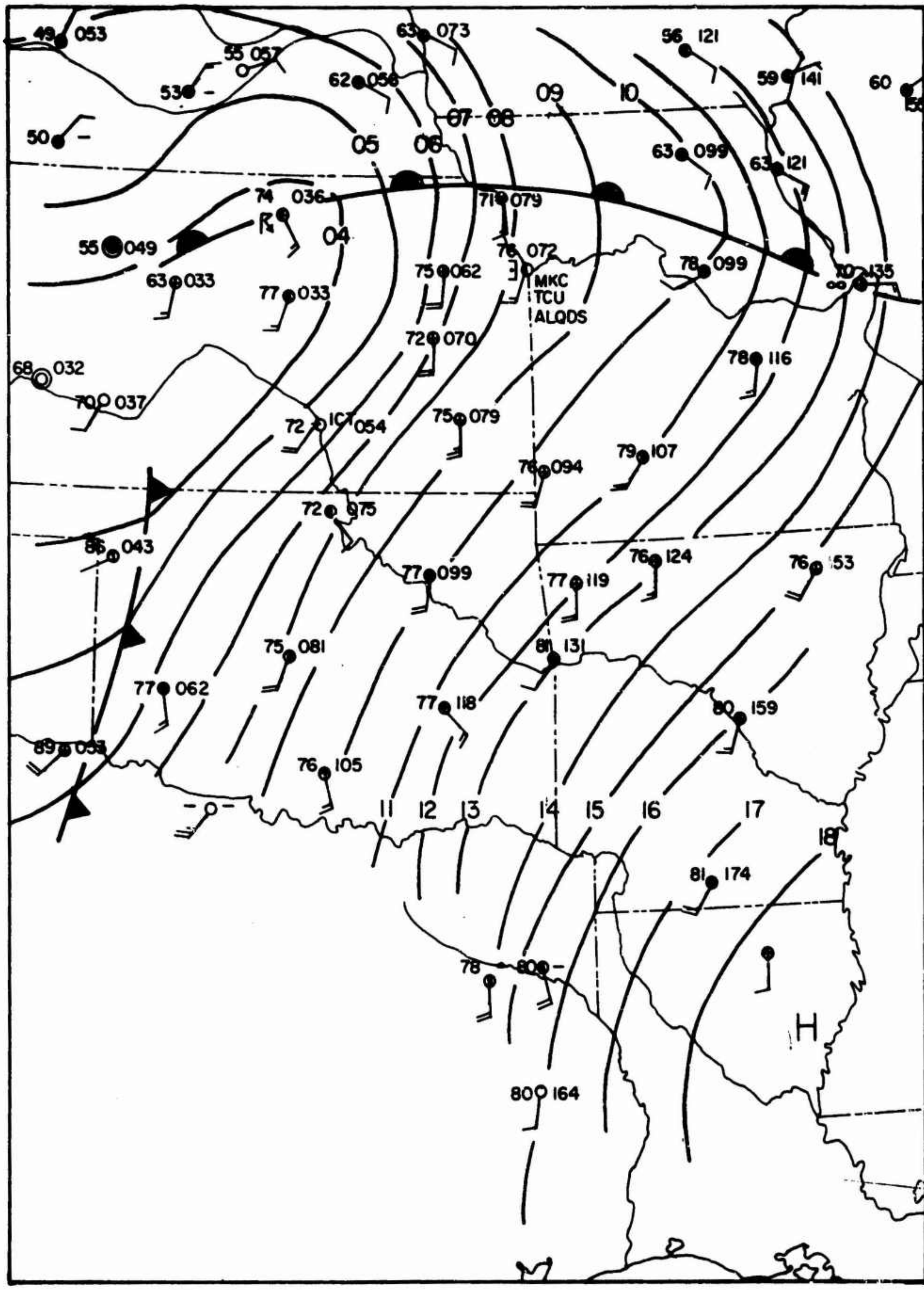


Fig. 4-10 Mesoscale Analysis at 1800 GMT, 20 April 1964

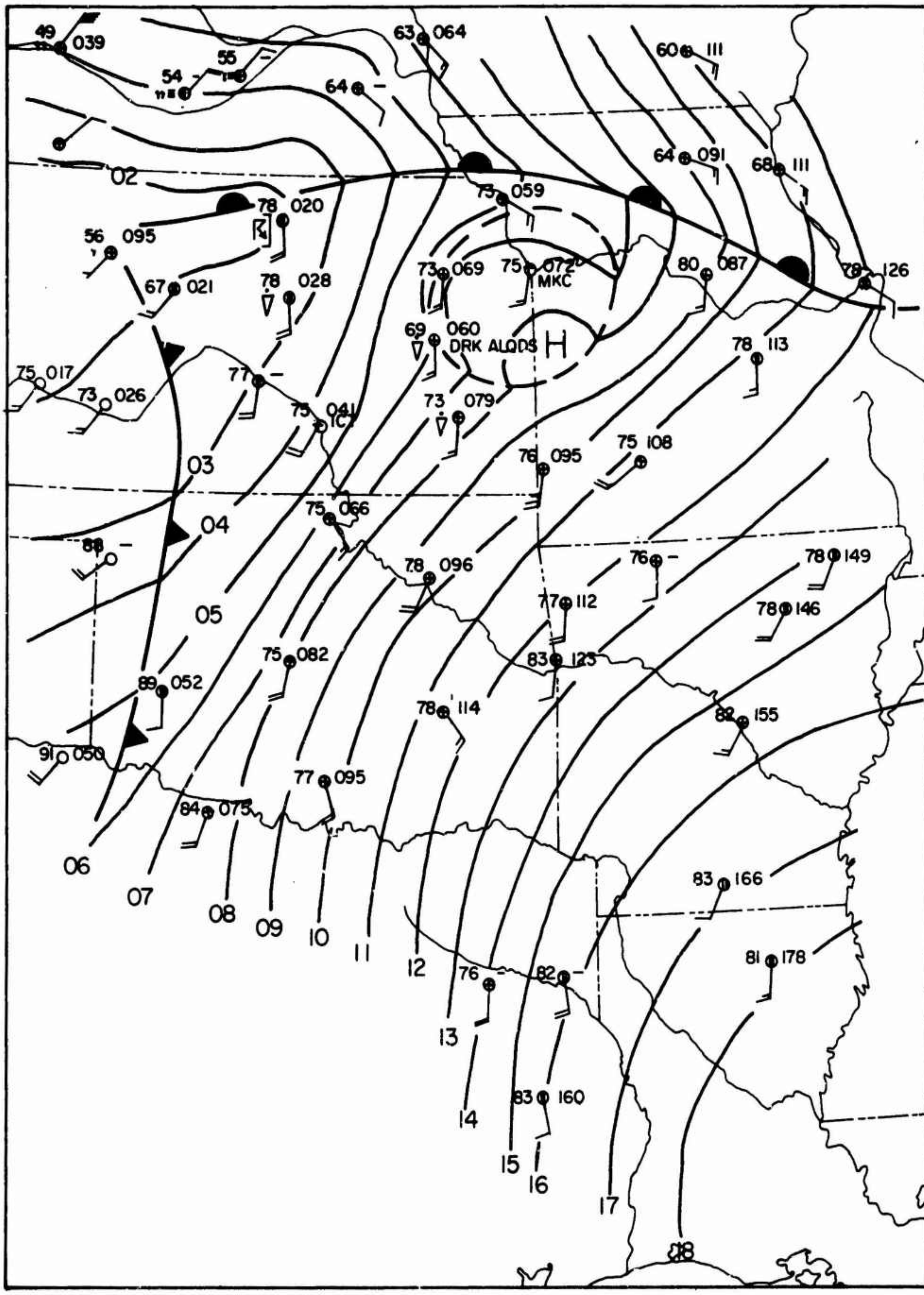


Fig. 4-11 Mesoscale Analysis at 1900 GMT, 20 April 1964.

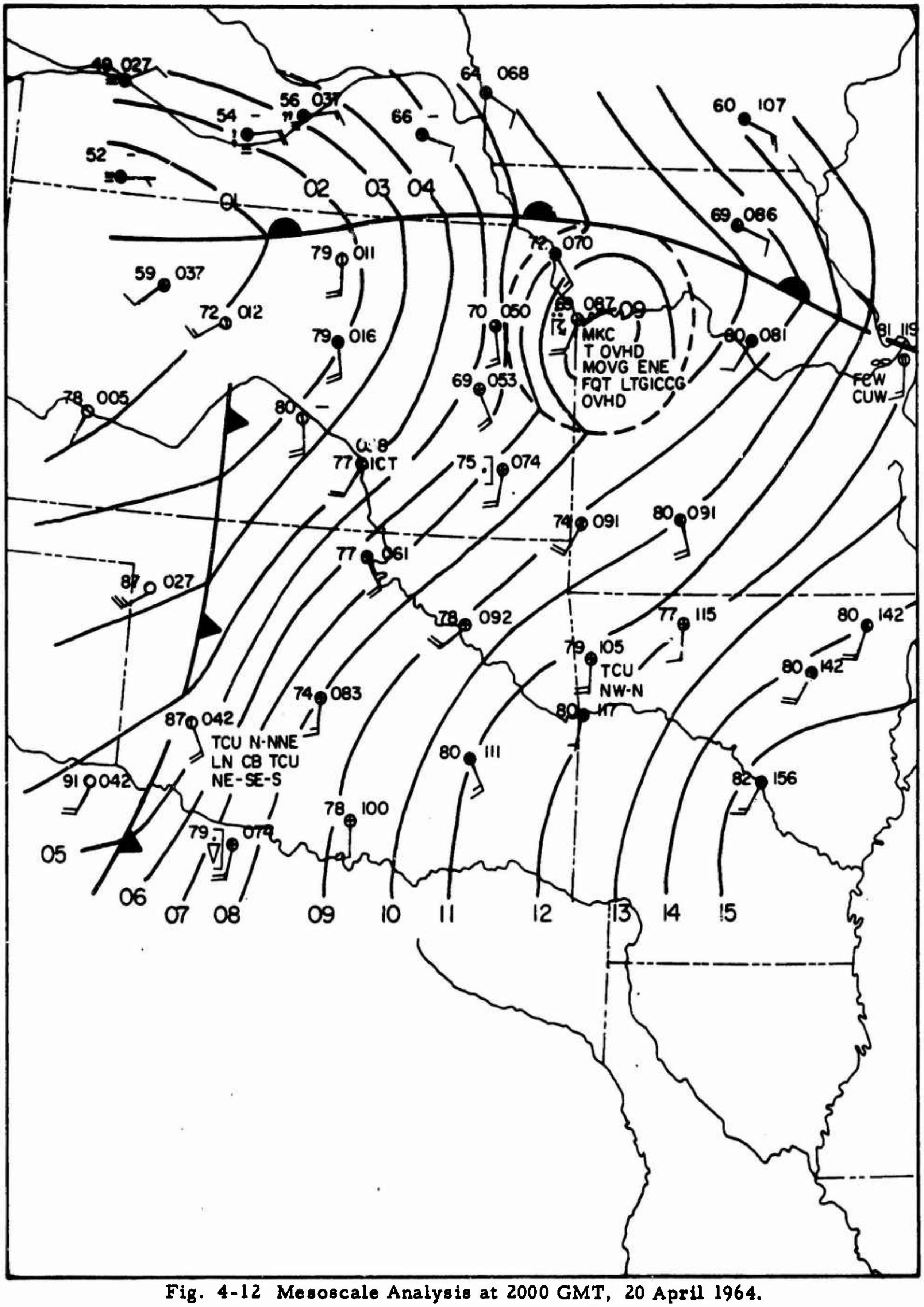


Fig. 4-12 Mesoscale Analysis at 2000 GMT, 20 April 1964.

There are, however, small storm shields without meso highs that can be recognized from an analysis of the hourly reporting network stations and conversely there are small meso highs without well-defined storm shields.

Most of the severe weather manifestations associated with this situation were concentrated in the path of line A-B and the large northern cloud mass and are symbolically depicted in Figure 4-9, along with the reported times of occurrence. The only verified tornado was a brief one in northeastern Oklahoma and occurred in proximity to line B-C.

Summary

In this case also, the magnitude and the bright rounded appearance of the northern cloud mass calls attention to this storm as a potentially severe one. However, some severe weather also occurred in connection with the line of clouds which extends southwestward from the principal cloud mass. This line feature is not commonly found in the satellite pictures of severe weather situations. All of the activity occurred within the warm air, south of the surface warm front, and was not related to either the warm front or the dew point front which is evident on the mesoscale maps over western Oklahoma. In this case, the satellite data indicated the presence of a severe weather situation where one would not be directly inferred from a careful surface analysis based on all data available.

4.1.4.3 Motion and Changes in Intensity of Thunderstorm Complexes Determined from Successive Satellite Passes

Satellite Data, TIROS VII, 1651 GMT (Fig. 4-13) and TIROS VI, 1822 GMT (Fig. 4-14) 28 June 1963

These pictures, one and one half hours apart and rectified in Figure 4-15, show a band of developing showers and thunderstorms which seem to originate near the Texas coast and then continue in a broad arc toward Florida. The most active development begins between 90° and 85°W and continues to and over the Florida peninsula, apparently attaining maximum stage of development over or near the Florida peninsula.

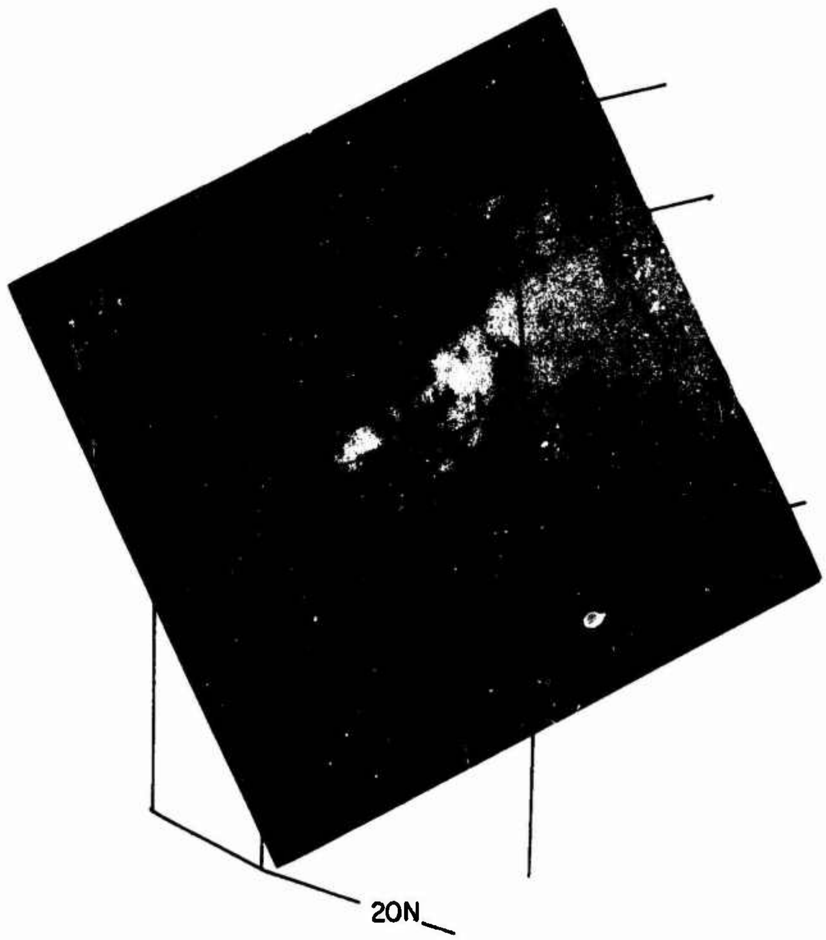


Fig. 4-13 TIROS VII Photograph at 1651 GMT, 28 June 1963, Showing Shower and Thunderstorm Clouds over the Gulf of Mexico.

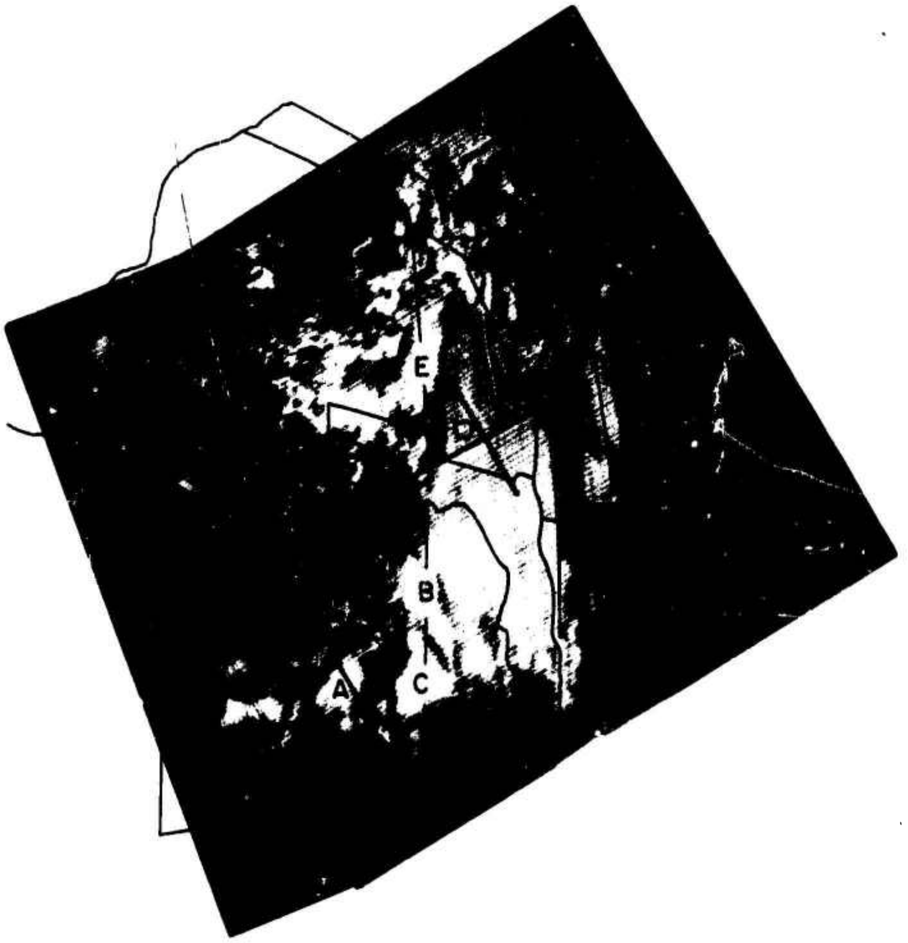


Fig. 4-14 TIROS VI Mosaic at 1822 GMT, 28 June 1963, Showing Changes in Clouds Observed 1-1/2 Hours Earlier in Figure 4-13.

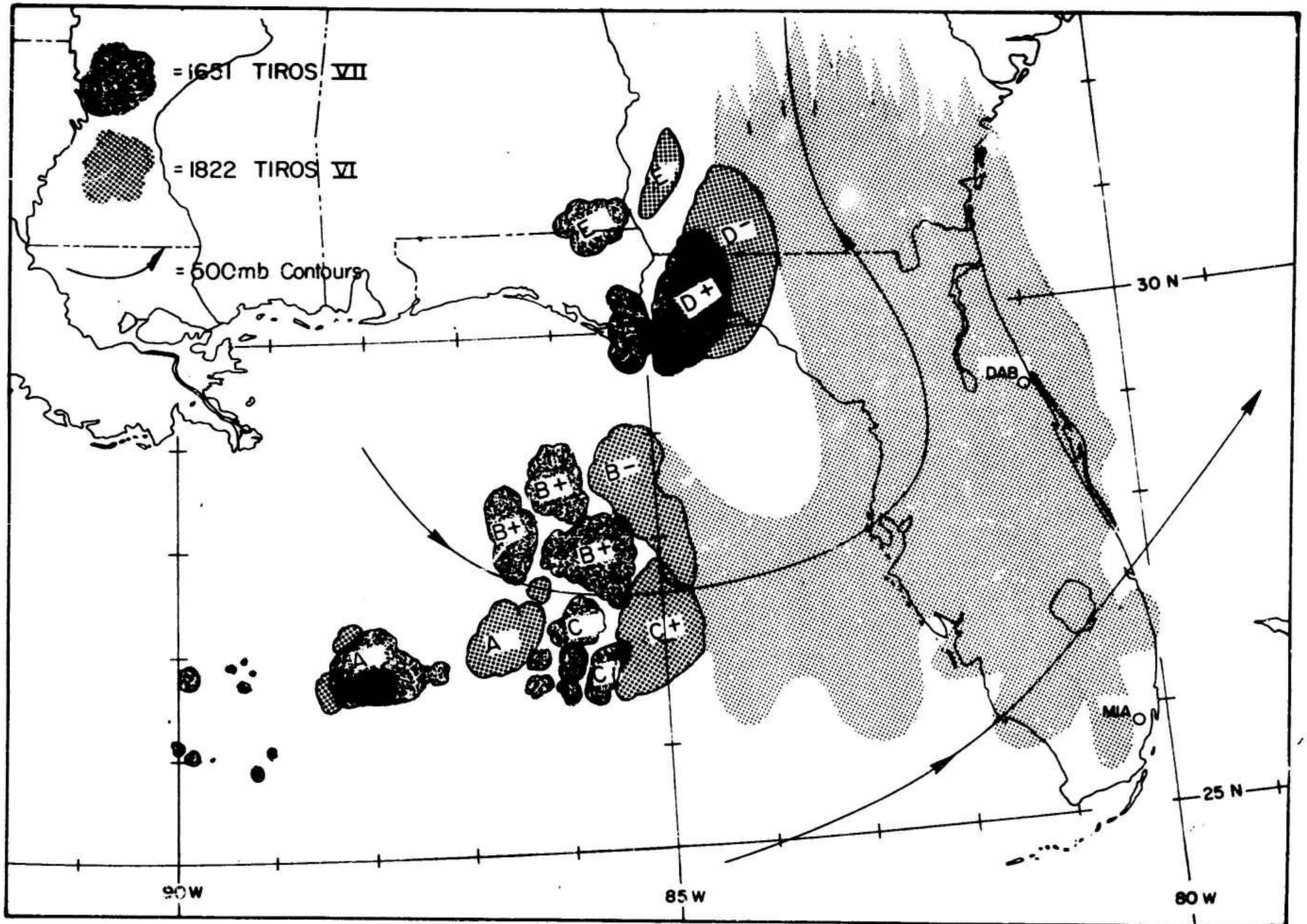


Fig. 4-15 Sketch Map of Rectified Positions of Significant Cloud Masses from Figures 4-10 and 4-14 Showing Displacement and Qualitative Intensity Changes in 1-1/2 Hours.

A careful examination of these pictures yields a number of useful pieces of information relative to the motion and development of the shower or thunderstorm complexes or, for simplification, "cloud units."

Motion

The one and one half hour span between these pictures appears to be about the maximum time over which "cloud units" can be identified from one picture to the next. By considering the general appearance and shape, and making allowance for development changes, it is quite possible to recognize some five cloud units labelled A through E in both Figure 4-13 and 4-14. In view of the high nadir angles and the absence of positive landmarks, measurement of cloud unit positions and displacements is somewhat uncertain. The results obtained for cells B and C is a motion from 250° at twenty-six knots; D and E gave 240° at twenty knots, while A was 260° at forty knots. Except for A, where the speed seems high, the other values are sensibly in agreement with the upper winds which are of the order of twenty to twenty-five knots from west to west-southwest.

Development

A comparison of pictures of the same field of view, but taken by two different satellites from different angles, creates considerable uncertainties in differentiating between those effects which are real and those caused by differences in the characteristics of the two systems or by differences in the viewing angles. The following qualitative deductions are made with these difficulties in mind. Unit A appears to undergo little change; size and brightness appear similar in both pictures. Unit B at 1651 GMT consists of several very bright cells with sharp edges. In the later picture B appears to have weakened appreciably; there is a reduction in brightness, the edges have become less sharp, and definite rifts have developed between the adjacent cloud masses. Unit C, on the other hand, appears to behave in the opposite manner. In the early picture, C consists of an assemblage of moderately bright cells. In the second picture, C has a much brighter appearance - that of an overall cirrus canopy but with sharp edges still evident. Unit D is very bright in Figure with the appearance of a dense cirrus canopy. In Figure 4-14 , D has become appreciably less bright and weaker with a fuzzy outline. Finally, unit E seems to undergo little change.

Since most of the pertinent cloud areas were over the Gulf of Mexico, mesoscale analyses were impossible. Radar data was limited to Daytona Beach, which was out of the range of the cloud units discussed above. The radar does indicate, however, that the motions of cells off the Florida West Coast average thirty knots from 230°. This is in general agreement with the motion obtained from the satellite pictures.

Summary

Given two pictures of the same area of thunderstorm development within one and one half hours or less, it is quite feasible to recognize individual units of clouds, their development from one picture to the next, and the direction and rate of their movement. Changes in intensity of these units appear to be recognizable, although verification of these results by radar is desirable. An interesting feature discovered in this brief investigation is that most of the cells within the cloud units as defined here, undergo changes in intensity more or less as a unit. At the same time, separate units which may be adjacent to each other may change intensity in opposite ways. For example, unit C intensified while unit B decreased in intensity in the same time interval.

4.1.5 Conclusions and Recommendations

On the basis of an analysis of seventeen cases in which prominent cloud masses, resulting from multiple thunderstorms, were observed from TIROS satellites, the following conclusions may be drawn:

1. The diameter of the cirrus shield, resulting from an integration of anvil clouds from a thunderstorm complex, is an index of storm severity. In the sample studied, the frequency of occurrence of damaging winds or tornadoes ranged from one out of seven for storms whose cirrus shield was sixty nautical miles or less in diameter to three out of three for storms having large cirrus shields of more than one hundred and fifty nautical miles in diameter.

2. With suitable interpretation, the satellite picture furnishes the clearest, most up-to-date and most detailed synopsis of the current state of cloud cover obtainable from any single source of data. In spite of this, it is recommended, whenever possible, that the satellite data be used only in combination with other data

such as radar and hourly surface observations. These other forms of data, when combined with the satellite pictures, add substantially to the prognostic information.

3. The only basis for extrapolating the motion or the intensity of thunderstorm complexes, using only satellite data, would be a series of two or more observations at intervals of one to one and one half hours. A single picture furnishes few reliable clues as to the future motion or intensity. In lieu of multiple pictures, radar observations at intervals of a half hour (interpreted in accordance with AWS TR 184) will furnish a basis for short range predictions of the motion and probable intensity of thunderstorm complexes. Lacking radar, a rawinsonde observation will furnish a basis for estimating the direction and speed of individual thunderstorm cells. Further estimates of the motion of the complex composed of these cells may be made by utilizing concepts given by Newton and Fankhauser (1964) (Reference 24).

Finally, it must be emphasized that while satellite pictures of cloud cover furnish the field meteorologist with a convenient, readily interpretable pictorial display of weather processes; they do not eliminate the necessity for obtaining and applying other forms of data if an optimum utilization is to be made.

4.2 Phase 2 - Atmospheric Structure and Air Mass Characteristics From 0.5 Nautical Mile Resolution Photographs

4.2.1 Introduction

The Advanced Vidicon Camera System (AVCS) which has been briefly described in Section 1 is designed to provide a transmitted picture resolution of one half mile at an altitude of approximately five hundred nautical miles. Tests of the Nimbus I AVCS indicate that the working resolution of this system was very close to its design value. This improved resolution provides sufficient additional information to allow cloud type identification. A single cumulus cloud which is between a half mile and one mile in size is the smallest cloud unit which can actually be seen. Other clouds having smaller unit sizes are identified indirectly by means of "texture." "Texture" is a combination of the shape, pattern, mode, and brightness of the cloud. Discussions below will indicate that identifying clouds becomes a matter of recognizing various combinations of these identifiers. Experience with Nimbus I has demonstrated that cloud types can be readily recognized. This immediately upgrades the meteorological information available about a cloud pattern. No longer does the meteorologist simply know whether there is cloud or no cloud or whether it is cumuliform or stratiform

but he knows whether it is cumulus, stratocumulus, or stratus; he can recognize middle clouds and can distinguish cirrus from other clouds. Cloud arrangements become apparent. Cumulus streets are everywhere, wave clouds are a common occurrence in the lee of hills and mountains. These and other mesoscale cloud features are thus extremely well depicted by the AVCS. In order to capitalize upon the increased information content of these data, it is necessary for the recipient to obtain the highest quality pictures possible and with sufficient dynamic range to fully depict the cloud identifiers - otherwise the advantages of improved resolution may easily be lost.

4.2.2 Meteorological Features in the Mesoscale Revealed by AVCS

4.2.2.1 Individual Clouds

Cumulus

The clouds that are more readily and unmistakably identified at half mile resolutions are cumulus. Plank (1962) Reference 27 determined that the cumulus clouds which account for the greater portion of the cloud cover are of the order of a half mile or more in diameter. These, therefore, fall within the resolution of current AVCS design. A study of the Nimbus I photos taken during August and September 1964, showed the very high frequency of occurrence of cumulus clouds over land areas of middle and low latitudes. While there is redundance in this type of information, the depiction of fields of cumulus clouds (in particular, their arrangement into streets, rows, or clusters) when properly interpreted, can shed light on the mesoscale circulation of the atmosphere.

The degree of development of the individual cumulus clouds provides information about such parameters as stability which aid in determining the state of the atmosphere. The presence of dynamic systems which may either promote or restrain convection, may also be indicated by the cumulus development. In this role, the clouds themselves are used as sensors of the atmosphere and its cloud forming processes.

Cumulonimbus

The ultimate stage of a cumulus is the cumulonimbus. The AVCS unmistakably identifies cumulonimbus since even the smallest unit of this cloud is well above the half mile limit of resolution. These clouds are identified by their somewhat rounded, brilliant white appearance. In their earlier stages, cumuionimbus may appear sharply outlined but as they mature there is often a fuzzy streamer or plume extending away from the main cloud. This represents cloud streamers of ice crystals which are being swept out of the anvil. The significance of this plume has been discussed under Phase 1 above (Section 4.1).

Figure 4-16 is a Nimbus I AVCS Picture showing a portion of southeast Texas and the Gulf coast. There is an extensive field of relatively small cumuli whose size range is estimated at a half mile to two miles in diameter. In contrast to the cumuli, a nascent line of cumulonimbi in various stages of development can be identified near the coastline. The smaller units of this line, near the bottom of the picture, are about twelve nautical miles in diameter. The largest cumulonimbi shown are about forty-two nautical miles in diameter and are undoubtedly comprised of a number of convective cells. Their fuzzy outlines are characteristic of mature thunderstorms in which the anvil material is being transported laterally.

4.2.2.2 Organized Clouds

Cloud Clusters or Aggregates

The well known "U" shaped distribution of cloud cover, as observed from the ground, is evidence that clouds do not often nor long exist as distinctly separated units. In fact, the characteristic mode of existence of most clouds, with the exception of the simplest cumulus of fair weather, is in clusters, complexes, or aggregates. These range from the mighty cumulonimbus complexes, generators of severe weather, which have been discussed at length in Phase 1, to vast sheets of stratocumulus and altocumulus.

One noteworthy feature of cumulonimbus complexes, as viewed by meteorological satellites, is the infrequency of their arrangement into lines. For many years, the term "squall lines" has been used to refer to what has been depicted on weather charts and later on radar as a line of thunderstorms ranging to several hundred miles in length. This arrangement, however, is seldom in evidence in the

Fig. 4-16 Orbit 343, Camera 3, Frame 7. Photograph of Southeast Texas and Gulf Coast with Extensive Field of Small Cumuli and Nascent Line of Cumulonimbi.

satellite photos, even when a line formation may be indicated on the radar and on the surface weather map. While the thunderstorm cells and aggregates of cells are often aligned, the cirrus from the anvils levels merge and form a pattern which is in the shape of a more or less circular "blob." However, there are exceptions -- but usually squall line phenomena occur with no recognizable line in the satellite photo. A discussion of clues indicative of severe weather will be found in Section 4.1.

A grouping of clouds which is very common in Nimbus AVCS photos is the now-familiar cloud street. TIROS resolutions permit seeing cloud lines which result from unequal spacing or merging of cloud streets -- but the individual basic cloud streets themselves are not resolved. The AVCS resolution, however, does reveal the individual cloud streets which are from one to two nautical miles apart (Fig. 4-17). The streets have been found to be oriented parallel to the shear between the low level wind and the wind at the cumulus tops. The shear in turn is usually found to be parallel to the low level wind, and thus the streets are generally parallel to the low level wind. The 180° ambiguity in direction can usually be resolved by noting the growth pattern of the clouds in the vicinity of land-water discontinuities. Thus, cloud streets can provide a very useful clue to determining the low level wind.

Akin to cloud streets, and sometimes found together, are cloud rows which form in a direction more or less perpendicular to the wind. In some cases, the rows appear as an alternating enhancement and suppression of the cumulus clouds in the streets. In the AVCS pictures, the two modes are readily distinguishable (Fig. 4-18).

Cloud Sheets

An extensive cloud area may develop from one of two principal causes: (1) extensive cooling from below with stable conditions above - resulting in a stratus or stratocumulus cloud deck, or (2) a general area of widespread lift - usually resulting in a region of multi-layered cloudiness.

The high resolution AVCS will readily distinguish between these two types of cloudiness which may have a very similar appearance at TIROS resolution.

Stratocumulus and stratus clouds can be identified in the Nimbus AVCS. These occur in patches or areas having rather sharply defined edges (Fig. 4-19). In many cases, these clouds appear greyer than other continuous cloud forms, although this is probably a function of the cloud depth. The stratocumulus exhibits somewhat more texture and is brighter than the smooth stratus.

Fig. 4-17 Orbit 79, Camera 2. First Order Cloud Streets in a Southeast Flow of Hudson Bay and North of a Cyclonic Cloud System. Note Cloud Rows in Extreme Upper Left.

Fig. 4-18 Orbit 324, Camera 2, Frame 5. First Order Cloud Streets (parallel mode) and Cloud Rows (normal Mode) Occurring Together in a Westerly Flow Over England Behind a Cold Front.

Fig. 4-19 Orbit 310, Cameras 2 and 3, Frame 1[illegible]. Patches of Stratocumulus West of the Iberian Peninsula. Note Patterned Texture and Sharp Transition Between Cloud and No Cloud.

An area of continuous cloud cover having a dimension of one hundred and fifty miles or more located over a land area will ordinarily be composed of multiple cloud layers (Fig. 4-20). Such an area will display an irregular forward edge (in the downwind direction) showing disorganized patches of clouds, both middle and high, which seem to originate from the organized overcast. Billow or wave clouds, which for the most part are middle level clouds, are frequently found in this forward region. The high resolution of the Nimbus AVCS permits positive identification of these conditions. Frequently, it is possible to take advantage of breaks or holes in the cloud area. These reveal the presence of several cloud layers and at times even the development of cumulus when the holes are large enough. The rear edge of the cloud area may at times be quite sharp, with a rapid transition from overcast to clear or scattered.

4.2.2.3 Cloud Cover

Another significant advantage of AVCS resolution is the accurate determination of cloud cover, even when the prevailing coverage is in the 0.8 to 1.0 category. The ability to distinguish between a solid overcast and an overcast with breaks is considered very important. This distinction may enable a meteorologist to estimate the relative intensity and trend of a storm area and make it possible to discriminate between areas of high and low probability of precipitation, to give only two examples. Details of the location of breaks in a cloud cover, their persistence, and future displacement are pieces of information considered to be of great importance to the military.

4.2.2.4 State of the Atmosphere - Cloud Forming Processes

On the basis of a limited experiment performed using Nimbus I AVCS data and conventional rawinsonde data, the feasibility of estimating the structure of the lower atmosphere and the cloud producing process has been established. This technique applies particularly well to areas of relatively homogeneous clouds, where the cloud form as seen in detail in the photos, responds to such influences as cold air advection, upper level subsidence inversions, moisture advection, as well as interactions with large scale vertical motion systems.

Figures 4-20 and 4-21 demonstrate how the Nimbus AVCS data may be interpreted in terms of the large-scale atmospheric processes and the structure of the lower troposphere. Figure 4-20 is a montage of frames 3, 4, and 5 of orbit 314 over

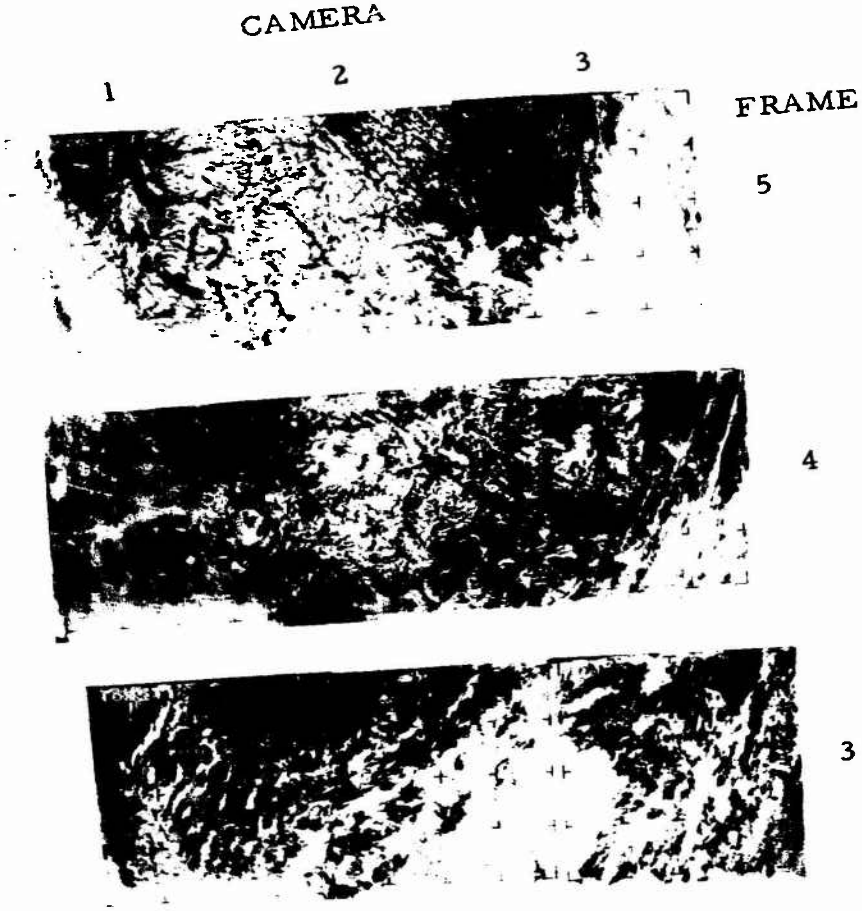


Fig. 4-20 Montage of Frames 3, 4, and 5, Orbit 314, Demonstrating the Use of Nimbus I AVCS Data in Estimating Atmospheric Structure and Large Scale Cloud Forming or Dissipating Processes.

Fig. 4-21 Map of Principal Cloud Features Rectified from the Pictures in Figure 4-20, Showing Areas A and B Discussed in the Text.

the western United States. Figure 4-21 is a schematic representation of the principal cloud features shown in the pictures. Illustrated here will be the interpretation of areas A and B as identified in Figure 4-21.

Area A is an area of heavy swelling cumulus, as indicated by the sharp cellular appearance. The extensive cloud cover, overcast in many areas, indicates a spreading out of the tops but there is little indication of glaciation and, hence, no cumulonimbi. In addition, in frame 3, camera 2, there are heavy cumulus streets. All of these clues point to the same thing: an area of strong cold advection in the lower levels producing a steep lapse rate. The flattening indicates an inversion capping the convection, most likely a subsidence inversion. Figure 4-22a shows two Radiosonde ascents at Glasgow, Montana (location 1 in Fig. 4-21) in the path of the cold air. These soundings, twelve hours apart, demonstrate the cold air advection which resulted in the clouds in area A. To be especially noted is the strong cooling below 550 mb and the consequent development of a very steep lapse rate. In this environment, lower level convection would be uninhibited, but largely capped by the subsidence inversion in the vicinity of 600 mb.

Area B, seen mainly in the frame 5, camera 2 picture, is interpreted to be a multi-layered cloud area. Based largely on past experience, such extensive cloudy regions are generally found related to areas of upward vertical motion. This particular region is relatively small and several holes can be seen in it, indicating that the air which is being lifted was rather dry initially or that the vertical motion is not very strong.

The sounding chosen as most illustrative of this area is that for Ely, Nevada (Fig. 4-22b), estimated to have been inside the western edge of area B at 1200 GMT on 18 September (location 2, Fig. 4-21). On this sounding there is a near (ice) saturated layer above 540 mb in which the lapse rate is moist adiabatic, indicative of air being lifted on a large scale. Below this level, the air is quite dry with a near constant mixing ratio and a lapse rate approaching the dry adiabatic above 730 mb, supporting the idea of large scale lifting. It also indicates little or no precipitation and possibly an inflow of low level dry air from outside the area. The sounding at 0000 GMT on 19 September, following the advection of the cloudy area eastward, is one typical of strong downward motion (subsidence). There is a marked drying above 570 mb, a stabilization and a noticeable warming above 500 mb. The subsidence can be surmised from the cloudless area to the west seen in frame 4 and 5 of camera 1.

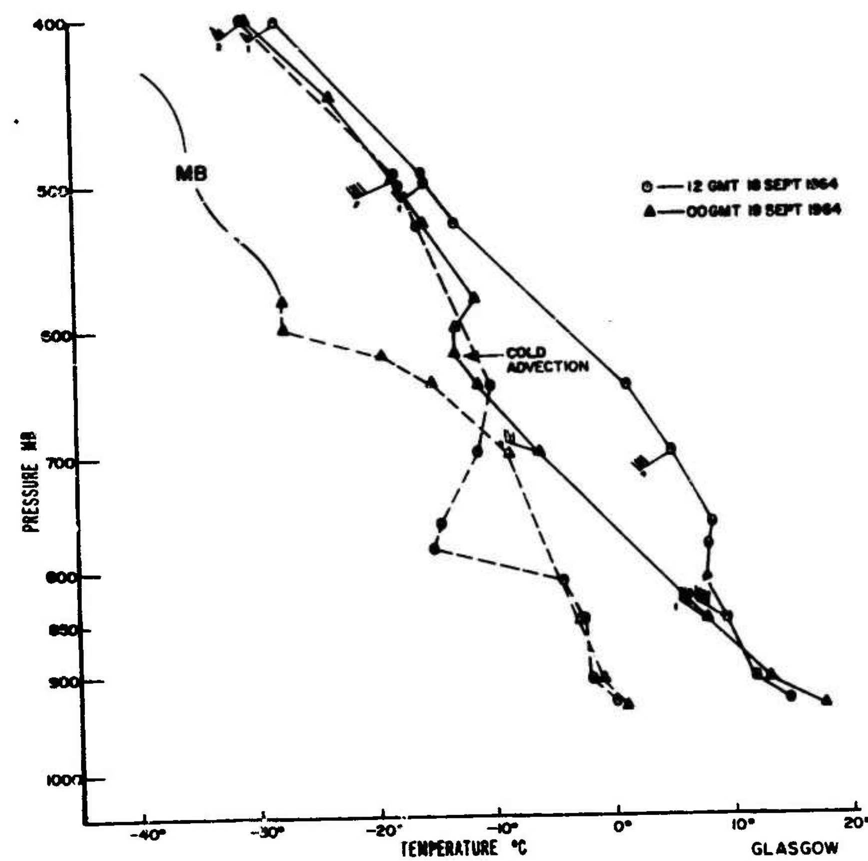


Fig. 4-22a Radiosondes at Glasgow, Montana.

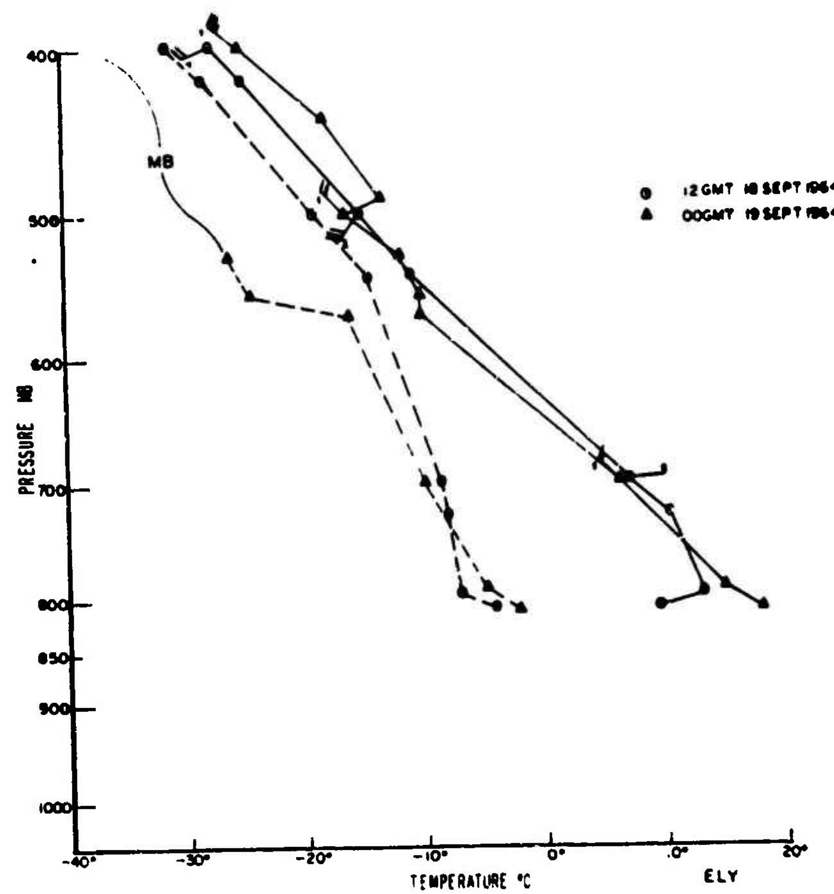


Fig. 4-22b Radiosondes at Ely, Nevada.

Evidence has been presented demonstrating that high resolution cloud photos such as provided by the Nimbus I AVCS may be useful in estimating the atmospheric structure, i.e., lapse rate, presence of inversion, and availability of moisture and deducing the atmospheric process responsible for clouds or absence thereof.

4.2.3 Summary

A very limited test of the high resolution AVCS data as supplied by Nimbus I, clearly demonstrated some of the advantages to be gained by the increased information available.

The basic gain is made in cloud identification. This is fundamentally necessary for interpreting accurately the current state of the weather which in turn forms the basis of any prediction, be it for the next half hour or the next six hours.

4.3 Phase 3 - Cloud Persistence

4.3.1 Introduction

The persistence or lack of persistence of cloud features, once identified in APT pictures, is of great significance in certain military operations. In particular, the success of a close support aircraft reconnaissance or bombing mission might depend on the degree to which cloud features, observed before the mission, maintained persistence for a period of up to a few hours (i.e., the time period necessary for completion of the mission). The ability to predict the degree of cloud persistence that could be expected in a given cloud situation would be invaluable in answering questions such as: (1) will the features of an advancing cloud layer persist, allowing a reliable prediction of the time remaining for a mission that must be completed before cloud covers an area? (2) will a break, observed in a larger area of general cloud cover, persist long enough to allow aircraft reconnaissance or bombing of that area? (3) will a layer of broken clouds maintain their observed distribution (i.e., will uniform and undistorted translation occur) allowing bombing or observation of specified areas?

A study of cloud persistence in satellite pictures and its applicability to wind determination has recently been completed at ARACON (Reference 16). Because that study was specifically concerned with the feasibility of wind determination, it concentrated on the rigorous persistence of rather small and clearly identifiable cloud

features over time periods of one half to two hours. It was found that (1) certain types of clouds, as seen in satellite pictures, and (2) clouds associated with certain synoptic situations are more likely than others to maintain this detailed persistence. In most cases, the clouds demonstrating the greatest persistence are either low or middle clouds, the very clouds that would most affect close support air operations.

From the viewpoint of the Army, the ability to predict general persistence of the cloud features would generally be of greater significance than the detailed persistence considered above. In an attempt to determine which cloud features might be expected to maintain useful general persistence over time periods of up to a few hours, a number of the cases used in the earlier study were re-examined.

4.3.2 Case Selections

Some fifteen cases of general cloud persistence, as observed in pictures from TIROS IV through TIROS VII, were selected and reviewed for this study. All cases were restricted to the North American continent because of the ready availability of nearly concurrent conventional meteorological data. Each case consisted of at least two pictures of the same cloud feature, taken approximately one half to three hours apart. Such repeated coverage is provided either by sequential passes of two different satellites or by consecutive passes of a single satellite where, in either case, a common area is viewed. The previous study had shown that approximately fifty percent of the total available sample (some ninety cases) demonstrated general persistence. Elimination of the remaining fifty percent was due to a variety of reasons, including cases of poor film quality and/or opposing nadir angles in adjacent pictures, as well as cases where the clouds simply did not persist because of rapid changes or unstable meteorological situations.

While pictures were usually available from only two orbits, in a few cases when the pictures were taken near the northern limits of the orbits a common area was viewed on three consecutive passes. One such case with three pictures, which provided coverage over a period in excess of three hours, is shown in Figure 4-23.

In this case (Fig. 4-23), general cloud persistence is obvious; a meso-scale convective cloud mass is observed moving from the Gaspe Peninsula across the mouth of the St. Lawrence River to Anticosti Island and then across Mingan Passage. (The persistent white area surrounding and east of Prince Edward Island is principally or entirely sea ice, illustrating the problem of differentiating ice from clouds.) The accompanying schematic of this figure shows even more clearly the

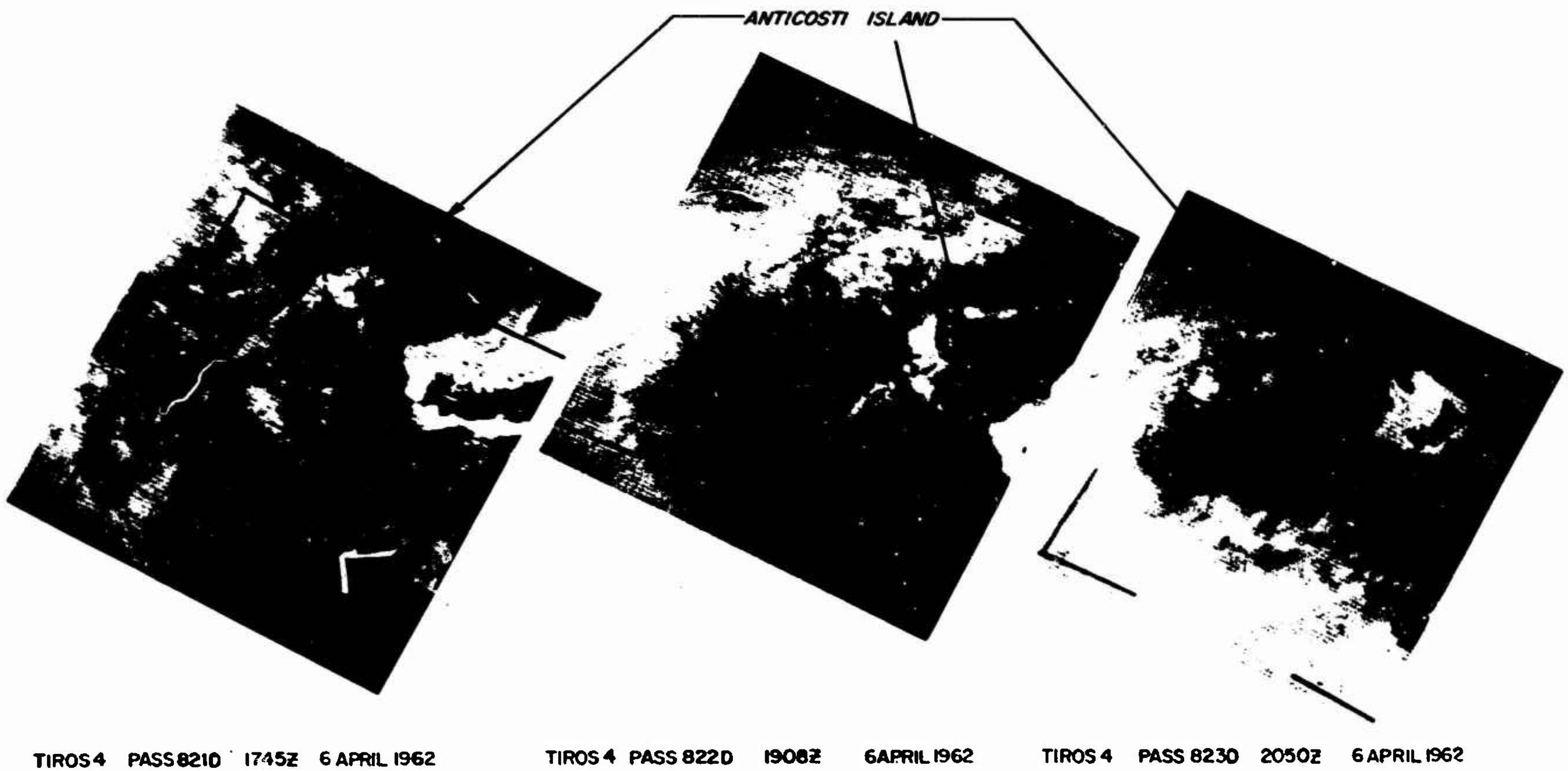


Fig. 4-23 Example of Cloud Persistence as Viewed in Three Consecutive Passes over the Gulf of St. Lawrence.

translation with time of this cloud pattern (Fig. 4-24). Also apparent in this case is an advancing cirrus shield, associated with a 500 mb short wave trough and surface warm front which are approaching the area from the west. Another case, observed over a similar three-hour period and over the same geographical area is shown in Figure 4-25. Here a break in a large area of cloud cover persisted for more than three hours as it moved eastward across the area over and east of Prince Edward Island. A common, fixed feature in all three pictures is the northeast edge of the sea ice. (This case is for a day later than that n Figure 4-23, and the persistence of the white area near Prince Edward Island confirms its identification as ice.) Figure 4-26 shows a large convective cloud band which persisted for more than one and a half hours over Baja and the Gulf of California. During this period of time, this band which is associated with a weak stationary front, obviously moved eastward.

4.3.3 Discussion and Results

Of sixteen cloud features which were studied, from the viewpoint of general persistence, twelve were synoptic scale features and four were mesoscale. Over the periods of observation there was definite translation in seven cases and little or no translation of six. In three cases, the amount of cloud translation could not be determined because of a lack of visible geographic features for reference.

The synoptic situation associated with each of the persistent cloud features was deduced from satellite observed cloud models and from the surface and 500 mb charts. The types of synoptic situations and the number of persistent cases associated with each, are listed below:

Mid-tropospheric (500 mb) short wave	7 cases
Mid-tropospheric (500 mb) wind maximum	1 case
Surface system with no definite upper air support	3 cases
Mesoscale convective activity	3 cases
Mesoscale non-convective activity	2 cases

The cloud type, as deduced from the character of the clouds in the satellite pictures, was determined for each case. The cloud types, as described in Widger et al (Reference 35) and Conover (Reference 7) and the number of persistent cases observed, are listed below:

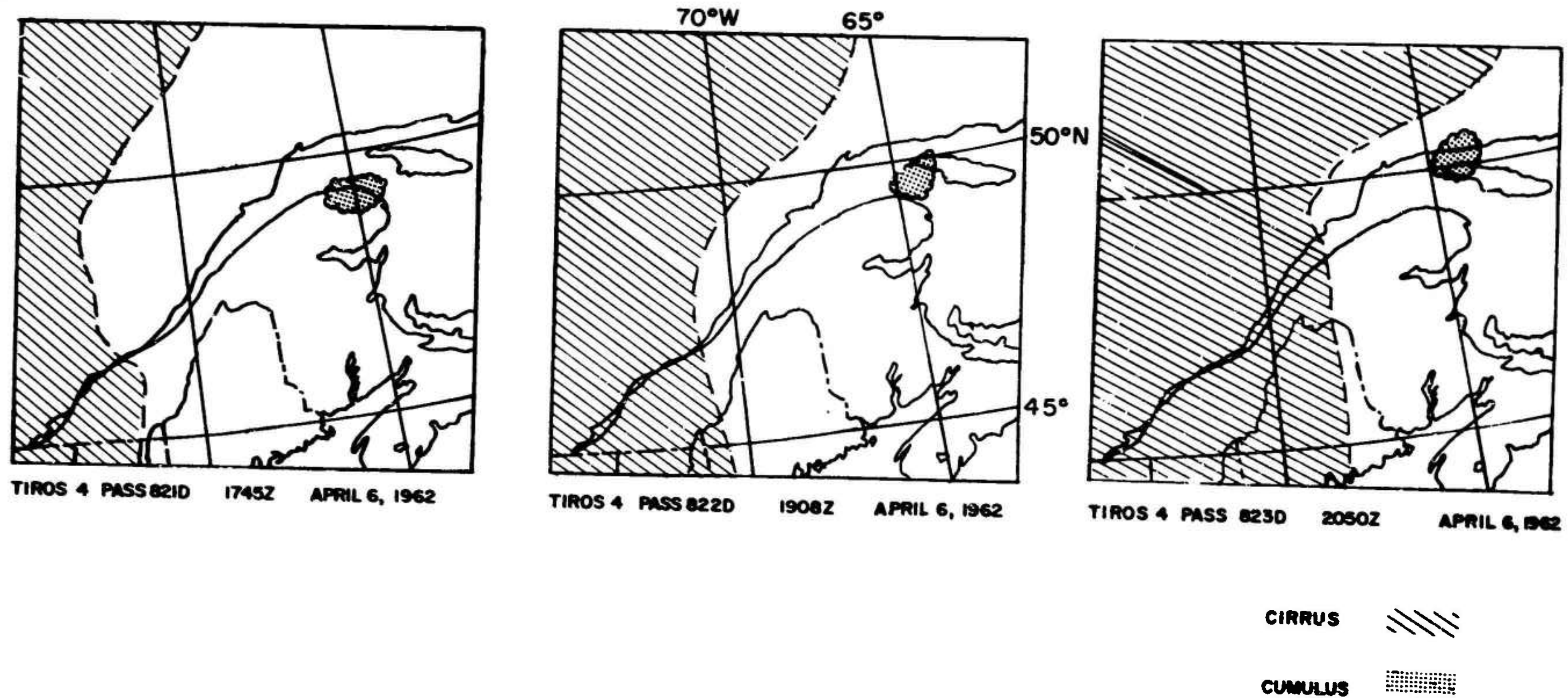


Fig. 4-24 Schematic of Features Shown in Figure 4-23.

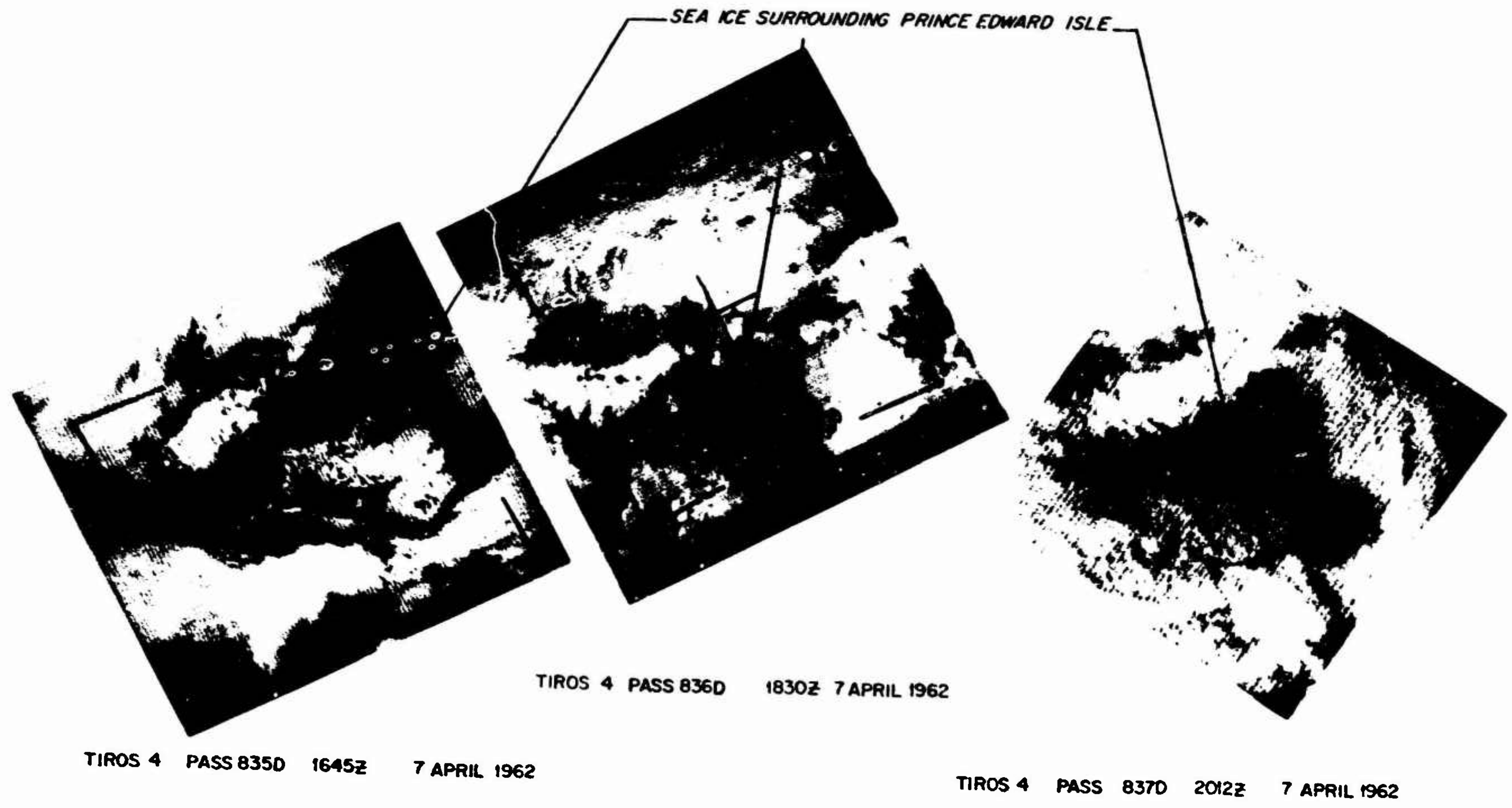
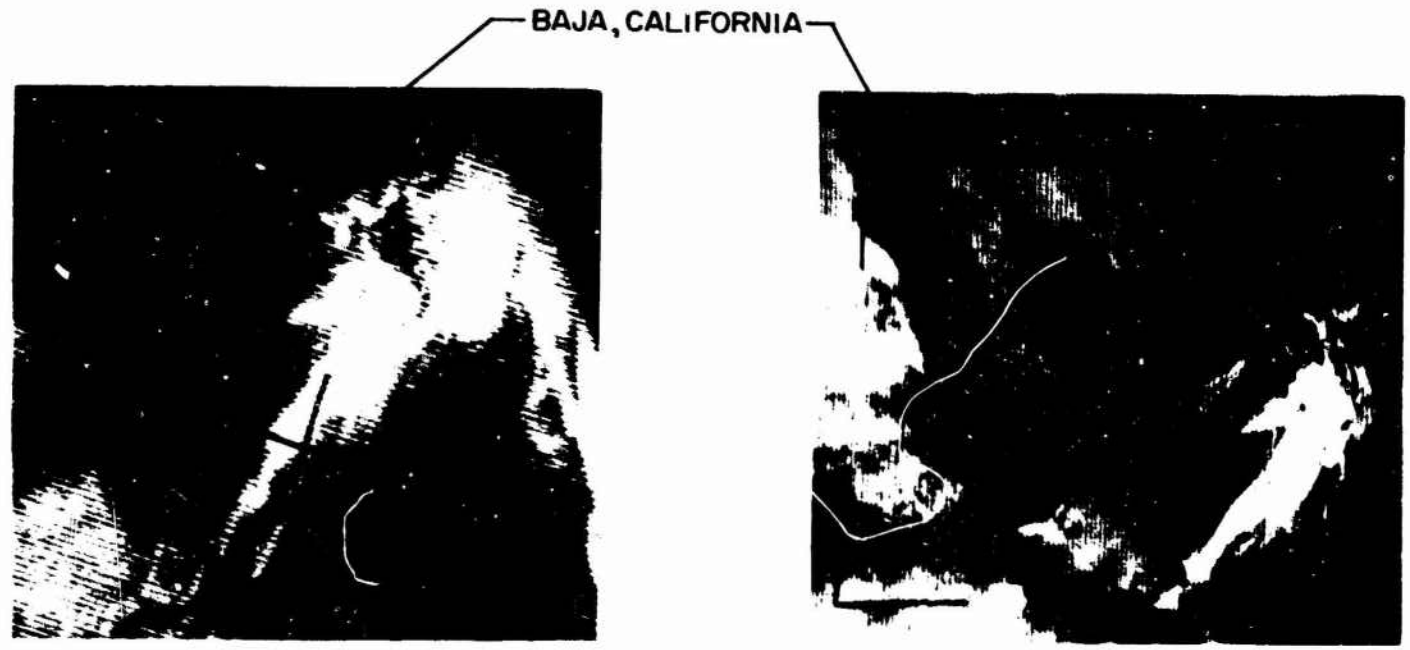


Fig. 4-25 Three Successive Passes Showing a Persistence Hole in Cloud Cover Near Prince Edward Island.



T-6 1917 Dir.
1856 GMT

T-5 3187/3186
2002 GMT

Fig. 4-26 Cloud Persistence and Translation Near Baja, California.

Cumuliform	11 cases
Fibrous stratiform	3 cases
Combination cumuliform and stratiform	2 cases

4.3.4 Tentative Conclusions

Nearly half of the persistent cloud features studied were associated with mid-tropospheric troughs or other flow patterns that are frequently associated with cloud formation. In previous studies, it has been pointed out that most cases of extensive satellite observed cloudiness can be related to flow patterns at their levels (Reference 35), so this result is not surprising and provides no basis for identifying persistent cases. Of significance is the fact that one characteristic is predominant among the sixteen persistent cases; i.e., in two thirds of the cases the clouds are the cumuliform appearing (or "lumpy"), which may include cumulus, stratocumulus, or cirrus (References 35 and 7). These clouds generally have well defined edges and may be in either masses or bands.

Persistent cases with a fibrous stratiform character included one case of filamented cirrus and two cases of stratus. While fibrous stratiform clouds very seldom maintain detailed persistence because of a lack of a well-defined cloud edge (Reference 16), it would appear that in at least some cases, the edges are well enough defined to maintain general persistence. Cumuliform appearing clouds are however, the more likely cloud types to maintain either detailed or general persistence.

No definite conclusions can safely be drawn from this limited data sample, but it does appear that certain cloud types whose characteristics are identifiable in APT pictures are more likely than others to maintain general persistence over time periods of from one half to two or three hours. Further studies would undoubtedly provide more complete and objective data on, and more rigorous techniques for predicting, general cloud persistence. Such studies would include an examination of a larger data sample utilizing more recent satellite data. With a larger data sample, more meaningful statistical relationships can be derived between cloud persistence and cloud type, synoptic situation, and time period. Because of the importance of cloud persistence to prudent Army applications of APT data, especially at the mesoscale, such studies should be undertaken at an early date.

5. WEATHER EFFECTS ON ENEMY OPERATIONS - TASK D

5.1 Short Term Effects of Weather on Enemy Operations

The short term effects of weather on enemy operations, including phenomena of a few hours to about one day duration, are of vital interest to the Army. In one World War II case, an enemy tank group become completely bogged down overnight when a heavy downpour flooded the low lying area where they were camped. Local severe weather, synoptic scale storm systems, and fog or low stratus conditions are all examples of situations when the short term effects of weather can greatly influence enemy operations.

5.1.1 Discussion

The major work under Task D was devoted to Phase 2, the long term effects of weather on enemy operations, since the short term effects are covered, at least in part, in other sections of this report. It is obvious that the results of such studies as the mesoscale studies of Section 4 and the cloud persistence study of Section 2.3 can be applied to the assessment of the effects on enemy operations as well as to the planning and implementation of friendly operations. Furthermore, much of the work completed under Phase 2 (long term effects) also has direct applications to shorter term problems, as discussed just below.

It is shown below, in Section 5.4, that the satellite data can give reliable indications of the daily occurrence of precipitation. Also, it is shown in Section 5.5 that the satellite can often delineate areas of fog cover. As might be expected, this study has confirmed that the short term effects of weather often depend upon the preceding weather. For example, a heavy rainstorm (possibly of tropical origin) may produce quite different results depending upon the state-of-the-ground at that time. If little precipitation has occurred during the preceding weeks, the ground may be able to absorb the moisture; if, however, the ground is near saturation from a period of copious rainfall, one further heavy rainstorm may produce severe flooding. Hence, the long term effects of the weather on enemy operations are often, in a sense, a summation of the effects of much shorter term weather phenomena.

5.2 Long Term Effects of Weather on Enemy Operations

In June 1950, the North Korean Army launched their attack against South Korea at a time when past and present weather conditions were of great advantage to them (Reference 25). During the weeks prior to the invasion, the weather had been extremely dry over North Korea, resulting in trafficability conditions that were ideal for the movement of troops and supplies both before and during the invasion. During the same period, wet weather prevailed south of the 38th parallel, providing poor trafficability conditions for the South Korean defenders. Since little or no weather information had been available from North Korea, the trafficability conditions to the north were largely unknown.

The Korean invasion is only one example of a situation where a knowledge of the weather conditions within enemy territory, integrated over a period of some weeks, would have been invaluable to the Army. In other Korean cases, landslides produced by a period of excessive rainfall delayed the advancing United Nations Army and dust resulting from dry weather caused equipment failures. World War II examples of wet or cold weather affecting enemy operation are numerous. It is obvious, therefore, that the long term effects of weather over enemy territory can be of significance to both enemy and advancing friendly Army operations.

The long term effects of weather are especially critical to Army considerations when anomalous conditions persist for periods of a month or so. For most parts of the world, climatic data exist to some degree enabling the Army to estimate the normal weather conditions over the enemy territory for particular months of the year. Thus, the effects of this normal weather on enemy operations can be evaluated. During periods of anomalous weather conditions, however, evaluations based on climatic normals would be misleading and might prove to be disastrous. Anomalous conditions that might exist would include: a month of excessive precipitation causing flooding, landslides, and poor trafficability; a period of heavy snowfall resulting in a breakdown of transportation and communications systems; a long dry spell producing dust and water supply problems; or a period of extreme cold resulting in equipment malfunctions and low troop morale.

The meteorological satellite is a means for obtaining vital weather information, even from enemy territory, as demonstrated in Section 4. The objective of this task was to determine if satellite data could provide an indication of long term anomalous

weather conditions over a particular region. Due to the relative lack of satellite observations over extended contiguous time periods and to the uncertainty of always having an observation over a particular region (until TIROS IX), very little work has been done previously on the climatological uses of satellite data. An ever increasing amount of work has been done in the investigation of various individual types of satellite observed meteorological features without specific regard to where they may be, but little work has been done with regard to comparisons of satellite observed cloud cover over a region from month to month or from year to year.

Sufficient satellite data have now been accumulated to make possible a semi-climatological type study. It is now often possible to find a region with adequate satellite coverage for corresponding months of two or more different years. In most cases, of course, the data are not as complete as would be desirable since few months have observations of every day. With the implementation of the ESSA operational system, however, this problem is reduced to a minimum, as was demonstrated during the early months of TIROS IX and ESSA 1.

In general, the approach during this task was to collect satellite data for a selected region, for the same season in different years, and to compare the satellite data with conventional climatic data for the same region and season. Data in the form of both operational nephanalyses and actual vidicon pictures were used for the study. Since the nephanalyses are more readily available and easier to work with, a study using only nephanalyses was first carried out to determine whether a study using actual satellite pictures appear justified. This study proved the desirability of performing this task. These results, and especially the results of the analyses of the picture data, prove the value of the APT data toward satisfying the needs of this task.

5.2.1 Case Selection

Monthly climatic summary maps of the United States were reviewed to find months during which particular regions reported significantly anomalous weather conditions. The United States was chosen for this initial study since both satellite and conventional climatic data were most readily available; one month periods were selected, since most climatic data are summarized on a monthly basis. Periods of excessive precipitation were given first consideration because of the satellite's prime capability for measuring cloud cover (which is at least partially correlated with precipitation) and because of the inherent effects of excessive precipitation on Army operations (References 25 and 26).

After the initial selection of possible cases had been completed, maps of monthly precipitation, expressed in terms of percent of normal, were consulted to obtain a better definition of the anomalous regions. A number of these cases were subsequently rejected because of insufficient satellite coverage of the region during the month in question. Since all of the cases initially selected were cases of excessive precipitation, another search of the satellite data was then made to find a corresponding month (preferably the same month in a different year) with adequate satellite coverage, but with a normal or below normal precipitation amount. In many cases, it was possible to find such a month. Using these pairs of months, the satellite data could be compared to determine if significant differences did exist. (If significant differences between pairs of more or less "extreme" months had not existed, it would appear unlikely that satellite data could be applied to climatological studies of this type.)

Later in the study, a few additional cases with large deficiencies in precipitation or with large temperature departures from normal were selected.

The final selection of cases is given in Table 5-1. In all, nineteen months of data comprising seven separate cases were examined. Each case is defined as two or more months of data for the same region, with at least one month having a positive precipitation (or temperature) anomaly and another a negative anomaly or no anomaly. In this table, the number of days with satellite coverage for each month is also given.

5.2.2 Data Selection

5.2.2.1 Satellite Data

The satellite data used were from TIROS V through TIROS IX. As Table 5-1 shows, there were more than twenty days of satellite data for all primary months (those months first selected because of an outstanding precipitation or temperature anomaly); for all but two of the comparative months, more than twenty days of satellite data were also available. As mentioned before, a study using only the operational nephanalyses was first carried out; nephanalyses were examined for all months shown in Table 5-1. After completion of the nephanalysis study, a study using actual pictures was made for selected cases. The picture study could not be completed for all months for which data were available because of the fraction of the total contractual resources that it was felt reasonable to allot to this task.

Table 5-1. Case Selection

Case Number	Region	Month	Days With Satellite Observations	Precipitation for Month (Percent of Normal)	Remarks
1	Southern Washington, Oregon, Northern California	December 1964	24	100 - 300%	Heavy Snow, Flooding
	Same	December 1962	19	50 - 100	Warm, Dry
2	Washington, Oregon, Northern California	March 1965	29	25 - 50	Very Dry
	Same	April 1963	24	150 - 400	Cool, Wet
3	Minnesota, Wisconsin	March 1965	26	100 - 300	Cold, Heavy Snow
	Same	April 1965	25	75 - 200	Wet, Flooding
	Same	March 1964	27	75 - 150	Cold, Normal Precipitation
	Same	April 1964	22	100 - 150	Normal
4	North Carolina South Carolina Eastern Georgia	May 1964	31	25 - 100	Very Dry
	Same	July 1964	28	75 - 300	Record Precipitation in Places, Flooding
5	South Carolina, Eastern Georgia	July 1964	28	150 - 300	Record Precipitation, Flooding
	Same	November 1964	26	50 - 100	Very Dry
6	Montana	February 1964	26	50 - 150	Dry, Very Warm
	Same	March 1965	30	50 - 100	Dry, Very Cold
7	Eastern New York Southern New England	May 1964	29	25 - 50	Very Dry
	Same	June 1964	21	50 - 75	Very Dry
	Same	September 1964	25	less than 50	Drought
	Same	October 1964	27	25 - 75	Drought
	Same	November 1963	13	150 - 200	Wet

5.2.2.2 Conventional Climatological Data

The optimum methods for the comparison of satellite and conventional data are not obvious since satellite cloud photographs cover areas several orders of magnitude greater than do single ground observations. This problem is pointed out by Blackmer and Alder (Reference 1) among others.* They demonstrate, however, that an averaging of the reports from a large number of observers, each located beneath the cloud cover of interest, would tend to smooth out the effects of the limited fields of view of the earth observer. Since this task is concerned with the typical weather for a given region and period, a number of ground stations were selected which, when considered together, are felt to be representative of the region. Local climatological data summaries (giving daily and monthly totals and averages) and monthly normals were obtained for the selected stations. The stations, along with their call letters (as given on most standard plotting charts) and the cases which they represent, are listed in Table 5-2.

Since a satellite provides only one (in rare cases, a few) instantaneous observation each day, the question arises as to the probability of a photograph at a given instant being representative of conditions over the day as a whole. It has been shown by Blackmer and Alder (Reference 1) that a given amount of cloud cover has a high probability of being the same six hours later. The probabilities decrease for periods of eighteen to twenty-four hours. In light of this, it is felt that the method of comparison of satellite and conventional data used in this task, and outlined below, is reasonable. The daily totals of precipitation and ground observed sky cover were averaged over all of the stations of a region to obtain a value representative of the region for that day. These daily average values were then used to obtain a representative monthly value. In this way, it was possible to compare various parameters on both a daily and a monthly basis.

5.2.3 Nephanalysis Study

5.2.3.1 Procedures

All nephanalyses available for the months selected were examined with each observation being considered as representative of its day. In a few cases, two satellites passed over a region on the same day, a few hours apart. In these cases,

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* See also Section 3.1 of the "Operational Guide" prepared under this contract.

Table 5-2. Climatological Data Stations

Case	Station	Call Letters
1	1. Eureka, California	EKA
	2. Red Bluff, California	RBL
	3. Medford, Oregon	MFR
	4. Burns, Oregon	BNO
	5. Portland, Oregon	PDX
	6. Pendleton, Oregon	PDT
	7. Spokane, Washington	GEG
2	1. Eureka, California	EKA
	2. Red Bluff, California	RBL
	3. Medford, Oregon	MFR
	4. Burns, Oregon	BNO
	5. Portland, Oregon	PDX
	6. Pendelton, Oregon	PDT
	7. Spokane, Washington	GEG
	8. Seattle, Washington	SEA
3	1. Minneapolis, Minnesota	MSP
	2. Duluth, Minnesota	DLH
	3. International Falls, Minnesota	INL
	4. Fargo, North Dakota	FAR
	5. Milwaukee, Wisconsin	MKE
	6. LaCrosse, Wisconsin	
4	1. Raleigh, North Carolina	RDU
	2. Hatteras, North Carolina	HAT
	3. Charlotte, North Carolina	CLT
	4. Charleston, South Carolina	CHS
	5. Columbia, South Carolina	CAE
	6. Augusta, Georgia	AGS
	7. Savannah, Georgia	SAV
5	1. Columbia, South Carolina	CAE
	2. Charleston, South Carolina	CHS
	3. Savannah, Georgia	SAV
	4. Macon, Georgia	
6	1. Great Falls, Montana	GTF
	2. Glasgow, Montana	GGW
	3. Billings, Montana	
7	1. Syracuse, New York	SYR
	2. Albany, New York	ALB
	3. Hartford, Connecticut	BDL
	4. Boston, Massachusetts	

Note: Refer to Table 1 for description of cases.

both observations were taken into consideration, but were counted as one observation. It is of interest to note that, in almost all of these cases, the overall cloud pattern had changed very little during the intervening period (seldom more than four hours).

Each nephanalyses was examined to determine the amount of cloud cover over the region, the extent of the cloud or cloudless area, the cloud type, and the probable synoptic situation (when it was possible to determine it). In the coding procedure used by the Weather Bureau for preparing nephanalyses, C is defined as > 80% coverage (covered), MCO = 50-80% (mostly covered), MOP = 20-50% (mostly open), and O = < 20% (open). Also, +C is coded when a cover of C is exceptionally bright. The number of days of +C, C, MCO, MOP, and O sky cover were tabulated for each month. Also, the average sky cover for each month was computed on the arbitrary basis of +C and C = .90 of sky cover, MCO = .65, MOP = .35, and O = .10. In some cases, a certain amount of subjectivity in determining the overall amount of sky cover for a region was inevitable since an average value of MCO could result either from the entire region having a sky cover of MCO or from part of the region having a cover of C and another part of a cover of MOP. Data tabulations were carried out for ten day periods, as well as for entire months. Both climatological normals and conventionally observed data were tabulated as described above.

5.2.3.2 Results of Nephanalysis Study

5.2.3.2.1 Comparison Between Satellite and Ground Observed Sky Cover

As a first comparison between satellite and ground observed sky cover values, the average sky cover for each month, as computed from the conventional data, was compared with the average sky cover as computed from satellite data. The ground observed values used were an average of the hourly observations of sky cover during the period of sunrise to sunset. (This value was used since many stations do not report midnight to midnight sky cover.) In all but one month, the ground observed sky cover was greater than the satellite sky cover with the average difference being equal to 1.4 of cover.

This difference between ground and satellite observed sky cover might arise from any or all of several sources. First, the methods adapted for computing the satellite sky cover might bias the average toward a lower value if a month had many days with 10 tenths (i.e., completely overcast) of satellite observed coverage. Since the designation C is used in the nephanalysis whenever the cloud cover is more than

80%, a value of 9.0 tenths was used in the averaging process wherever C was reported. Therefore, if most of the cases of C actually represented 9.0 tenths cover, the actual average value would be somewhat higher than the computations would indicate.

A second possible reason for the difference is discussed by Blackmer and Alder (Reference 1). The surface network views only a small fraction of the cloud cover, especially when low clouds are present and, therefore, ground observations do not always show the patchiness of a cloud cover. Holes in the clouds cannot be discerned until nearly overhead and may often be obscured by vertical development. Hence, the cover may actually be broken (not continuous) when a ground station is reporting overcast conditions. A third reason might be the failure of the TIROS cameras to detect many cases of small, scattered cumulus (References 7 and 35).

5.2.3.2.2 Comparisons Between Satellite Observed and Climatological Normal Sky Cover

A similar comparison was made between the satellite observed and the climatological normal sky cover for each month. It may be of interest to note that the average difference for all cases (approximately half of which had positive precipitation anomalies and half negative) is 1.3 tenths of cover. This is nearly the same value as the difference between the actual ground observed sky cover and the satellite observed sky cover, suggesting that the positive and negative anomalies of sky cover, in the sample studied, were about equal.

Table 5-3 summarizes further comparisons between satellite observed and ground observed sky cover. The close agreement between the values shown in Parts 3 and 4 of this Table are a further indication that the monthly fluctuations of sky cover observed by satellites are fully compatible with those observed by ground stations.

It is also to be noted in Table 5-3 that, on the average, months with above normal precipitation showed significantly greater sky cover (whether satellite or ground observed) than those with below normal precipitation. While this was expected, it did provide a first objective confirmation of the probable validity of the concepts on which the study was based.

Table 5-3. Comparisons Between Satellite and Ground Observed Sky Cover

1. Satellite Observed Sky Cover Minus Ground Observed Sky Cover: Average Value for All Months of Data	= -1.4 Tenths
2. Average Satellite Observed Sky Cover Minus Ground Observed Normal (Climatological) Sky Cover:	
a. Average for all months studied	= -1.3 Tenths
b. Average for all months with above normal precipitation	= -0.3 Tenths
c. Average for all months with below normal precipitation	= -2.0 Tenths
3. Satellite Observed Sky Cover, Approximately Corrected to Ground Observed Cover (i.e., plus inherent difference of 1.4 tenths), Minus Climatological Normal Sky Cover:	
a. Average for all months studied	= 0.1 Tenths
b. Average for all months with above normal precipitation	= 1.1 Tenths
c. Average for all months with below normal precipitation	= -0.6 Tenths
4. Ground Observed Sky Cover (average for month) Minus Climatological Normal Sky Cover:	
a. Average for all months studied	= 0.2 Tenths
b. Average for all months with above normal precipitation	= 1.1 Tenths
c. Average for all months with below normal precipitation	= -0.5 Tenths

5.2.3.2.3 Comparisons Between Satellite Observed Sky Cover and Monthly Precipitation Anomalies

Table 5-4 compares the satellite observed sky cover amounts and the monthly precipitation anomalies; the difference between the satellite observed and the climatological normal sky cover is used (instead of the actual value of the satellite observed sky cover) to emphasize the extent to which the satellite observed sky cover is above or below normal. (When considering Table 5-4, one should recall the apparent bias, discussed in the previous section, introduced when quantizing the satellite observed sky cover. Accordingly, satellite sky cover difference from climatology approximately -1.3 tenths should be considered as likely being above normal; those <approximately -1.3 tenths as below normal.) For this limited data sample, however, the correlation does not hold between the Above and Much Above months; also, the range of values for all categories is rather large (in some cases, the wide range is a result of one value being "out of line" with the others). Furthermore, some of the monthly precipitation amounts were only slightly above or slightly below normal.

From the results shown in Table 5-4, it can be stated with a reasonable degree of confidence, that if the (biased) monthly satellite observed cloud cover anomaly is near or above zero (i.e., satellite sky cover significantly greater than normal), the monthly precipitation is likely to be greater than normal. If the cloud cover anomaly is a large negative value (less than about -1.5 tenths; satellite sky cover less than normal), the precipitation is likely to be less than normal.

A comparison between the number of covered (C or +C) or mostly covered (MCO) days and the precipitation anomaly, is shown in Table 5-5. Percentages of observations are used in this table since the number of days with satellite observations vary from month to month. Even from this relatively small sample, the correlation between the percentage of days with sky cover of +C or C, and of +C, C, or MCO and the monthly precipitation anomaly is clearly evident. Again, the range of values are large for some categories.

Based on this sample, however, the following can be said with a reasonable degree of confidence: if the percentage of observations for a month that are +C or C is greater than 30%, the precipitation for the month is very likely to be above normal; if the percentage is less than about 15%, the precipitation will probably be below normal. Similarly, if the percentage of +C, C, or MCO observations is greater than 60%, the precipitation will most likely be above normal; if the percentage is less than about 35%, the precipitation will probably be below normal.

Table 5-4. Comparison Between (1) Monthly Satellite Observed Sky Cover minus Monthly Climatological Sky Cover, and (2) Precipitation Departure from Normal

Precipitation Departure	Number of Months	Average Value Satellite Observed Minus Climatological Normal Sky Cover (in tenths)	Range of Values
Much Above (≥ 200%)	3	-0. 7 tenths	0. 0 to -1. 3 tenths
Above (100 - 199%)	5	0. 0	+1. 2 to -2. 1
Below (51 - 99%)	7	-1. 6	-0. 7 to -2. 5
Much Below (≤ 50%)	4	-2. 6	-1. 3 to -4. 6
Above and Much Above (Combined)	8	-0. 3	+1. 2 to -2. 1
Below and Much Below (Combined)	11	-2. 0	-0. 7 to -4. 6

Satellite Observed Sky Cover Determined From:

+C, C = 9. 0 tenths (> 80% coverage)
MCO = 6. 5 tenths (50 - 80% coverage)
MOP = 3. 5 tenths (20 - 80% coverage)
O = 1. 0 tenths (< 20% coverage)

Note: When considering this table, one should recall the apparent bias, discussed in Section 4. 2. 2, introduced when quantizing the satellite observed sky cover. Accordingly, satellite sky cover difference from climatology > approximately -1. 3 tenths should be considered as likely being above normal; those < approximately -1. 3 tenths as below normal.

Table 5-5. Percentage of Monthly Observations That are +C, C, and MCO Compared with Monthly Precipitation Departures from Normal

Precipitation Departure From Normal	Number of Months	Average Percent of Observations	Range of Values	Average Percent of Observations +C, C, or MCO	Range of Values
Much Above ($\geq$ 200%)	3	32%	25 - 38%	79%	71 - 86%
Above (100-199%)	5	47	14 - 69	70	26 - 88
Below (51-99%)	7	17	8 - 30	51	42 - 60
Much Below ($\leq$ 50%)	4	12	10 - 14	38	17 - 48
Much Above and Above (Combined)	8	41	14 - 69	74	36 - 88
Below and Much Below (Combined)	11	15	8 - 30	46	17 - 60

<u>Definitions</u>

+C and C = > 80% coverage
MCO = 50 - 80% coverage

Other comparisons were made, such as between (1) the percentage of +C or C observations occurring within a ten-day period, and (2) the percentage of the total monthly precipitation occurring within that period. The ranges of values in these comparisons are too large for statistical significance; it can, however, be mentioned that in fifteen of nineteen months, the largest percentage of +C or C observations occurred in the ten-day periods with the largest percentage of precipitation. In eleven of nineteen months, the smallest percentage of +C or C observations occurred in the periods with the least precipitation.

5.2.3.3 Discussion of the Nephanalysis Study

Because of the limited resources available for this task, the work was concentrated on attempting to correlate satellite observations with precipitation anomalies. When working with precipitation anomalies, there are obvious problems involved when an investigation is based on nephanalysis data alone. The nephanalyses do not adequately depict the synoptic situation in most cases and often provide only a poor definition of the cloud type. A further major problem is that the majority of a month's precipitation may occur in just one storm, although there are many more cloudy days during the month. The nephanalyses may not be adequate to differentiate the one or few particularly significant days.

As discussed above, the correlations are not always statistically valid and even when they are valid, the ranges of values are often greater than desirable. However, the results of the nephanalysis study were adequate to demonstrate that satellite data can give an indication of precipitation anomalies for periods of ten days to one month. Based on these results, it was obviously desirable to extend the study, using the more detailed information provided by actual satellite picture data.

5.2.4 Direct Use of Satellite Pictures

5.2.4.1 Procedures

The satellite pictures for nine months of data, which provided five separate cases, were examined. (Picture data for Case 2 - March 1965, a below normal case complementary to that for April 1963, were not readily available.) The cases selected for study were those with large amounts of satellite data available and with suitable meteorological situations, as listed in Table 5-6. Working prints were made

Table 5-6. Case Selection for Picture Study
(Refer to Table 1 for Details)

Case Number	Region	Month	Precipitation Anomaly
1	Southern Washington, Oregon, Northern California	December 1964 December 1962	Much above normal Below normal
2	Washington, Oregon, Northern California	April 1963	Much above normal
3	Minnesota, Wisconsin	March 1964 March 1965	Below normal Above normal
4	North Carolina South Carolina Eastern Georgia	May 1964 July 1964	Below normal Above normal
5	South Carolina Eastern Georgia	July 1964 November 1964	Much above normal Below normal

of the proper frames from the pertinent TIROS film strips. Since the accuracy of geographic location was not critical for this effort, it was sufficient to use the nephanalyses for geographic referencing.

The pictures were examined in an effort to estimate the probability of precipitation associated with each observation and so, to arrive at an estimation of the integrated precipitation regime for that region during the particular month in question. Again, if there were two observations in one day, they were both examined and averaged subjectively to obtain one observation. The precipitation probabilities were compared with standard precipitation data; sky cover comparisons were not made during this part of the study since it seemed little more would be learned than what was deduced during the nephanalysis study.

5.2.4.2 Determination of Precipitation Probabilities

The satellite pictures were examined in terms of the amount of cloud cover over the region, the circulation pattern and probable synoptic situation (determined from previously derived synoptic models interpreted from satellite pictures (Reference 35), the cloud appearance, and the cloud type. Most of these parameters can be evaluated using only the pictures themselves.

In evaluating the pictures with regard to the probability of precipitation, the amount of cloud cover over the region was considered first. The second consideration was the circulation pattern and probable synoptic situation. Probabilities were based in part on whether a cyclonic circulation or frontal zone was obvious, where the center of circulation was in relation to the region, the degree of development of the circulation or front, and the probable rate of movement of the system. The third consideration was the cloud appearance with the cloud cover being examined for brightness (often showing apparent thickness; whether there were obvious thin spots or not) and texture (whether the cloud cover had a rough or smooth texture). Finally, the cloud type was taken into consideration; certain cloud types such as fibrous cirriform, stratus, and cumulonimbus "blobs," are easily recognizable in satellite pictures (References 13 and 35).

From the above evaluation, and using the results of previous studies of satellite observed cloud features (References 13, 22, and 35), a probability of precipitation occurring over all or part of the region in question was assigned for each day with a satellite observation. Four degrees of probability were established; they are: (1) very likely, (2) likely, (3) not likely, and (4) little chance. The

criteria for the probability of precipitation are given in Table 5-7, and examples are shown in Figures 5-1 through 5-7.

A degree of subjectivity was inevitable, at times, when selecting the probability. This was because a factor such as cloud brightness may vary greatly from picture to picture for non-meteorological reasons. For example, if an obviously well developed circulation (with very bright clouds) was observed moving over a region on one day, a high probability would be given for that day. On the following day, the same circulation might be observed over the region but, because of a non-meteorological factor such as camera angle or sun angle, the brightness may appear rather low. In this case, despite the low apparent brightness, a high probability of precipitation occurrence would be given.

5.2.4.3 Comparisons Between Precipitation Probabilities and Actual Precipitation Data

5.2.4.3.1 Comparison With Precipitation Occurrence

To obtain an indication of the validity of the probability criteria chosen, Table 5-8 compares the number of days on which precipitation actually occurred to the assigned probabilities. (In all of the following tables, the data are arranged by month according to the precipitation anomaly recorded for that month. The case numbers are given so that reference can be made to Table 5-1 for details as to the location of the regions.) The results of Table 5-8 indicate a high degree of validity for the probability selection. For all cases, precipitation occurred on 100% of the days assigned a probability of very likely, on 85% of the days assigned likely, on 35% of the days assigned not likely, and on none of the days assigned little chance. Overall, precipitation occurred on more than 90% of all days assigned probabilities of very likely or likely, or in all but two cases. Moreover, in most of the cases, where a rather high percentage of precipitation occurred on days assigned a probability of not likely, the high percentages are, in part, a result of the small number of days assigned this probability.

5.2.4.3.2 Comparison With Actual Precipitation Amount

Table 5-9 gives the amount of precipitation (averaged over the representative station) that was recorded on the days assigned each probability. The results shown

Table 5-7. Precipitation Probability Criteria from Satellite Pictures

Probability	Criteria	Cloud Cover Amount	Pattern	Appearance Brightness	Appearance Texture	Cloud Type Example
I. Very Likely	A.	More than 8/10	Organized	High	----	------
	B.	More than 8/10	Convective Groups	High	----	Cb Blobs
	C.	More than 8/10	Organized	High	Smooth	Ns
II. Likely	A.	More than 8/10	Organized, not organized, or convective	Low	----	------
	B.	5/10 - 8/10	Organized or convective	Low and/or patches of high	----	------
	C.	0 - 8/10	Organized or convective	High	----	Cb Blobs
	D.	5/10 - 10/10	Not organized	High	----	------
III. Not Likely	A.	0 - 4/10	Organized or convective	Low	----	Small Cu
	B.	0 - 4/10	Not organized	High	----	------
	C.	3/10 - 8/10	Not organized	Low	----	------
	D.		Organized	High	Smooth	Off Shore Stratus
	E.		Not organized	High	----	Filmy Cirrus
IV. Little Chance	A.	0 - 2/10	Not organized	Low	----	------

Legend:

1. Organized cloud patterns may include cyclonic circulation, banding, or solid cloud masses.
2. No entry in a column indicates that the particular subcriterion is not critical in that case.
3. To select a probabilility, any one criterion (such as A, B, or C) under that probability must be completely satisfied. If no criterion is completely satisfied, the next lower probability should be examined.

Table 5-8. Precipitation Probability Compared with Occurrence Of Precipitation

Case Number	2	5	1	3	4	3	4	5	1	Total or Average
Month	April 1963	July 1964	Dec 1964	Mar 1965	July 1964	March 1964	May 1964	Nov 1964	Dec 1962	All Cases
Percent of Normal Precipitation	236	211	200	195	179	90	85	76	63	------
1. Very Likely										
Total Days	1	8	4	6	11	1	3	0	2	36
Days with Precipitation†	1	8	4	6	11	1	3	-	2	36
Precent of Days with Precipitation†	100	100	100	100	100	100	100	-	100	100 (Ave.)
2. Likely										
Total Days	15	15	12	8	13	10	8	9	6	96
Days with Precipitation†	15	13	11	7	12	10	4	5	6	83
Percent of Days with Precipitation†	100	87	92	88	92	100	50	56	100	85 (Ave.)
3. Not Likely										
Total Days	5	5	2	4	4	12	12	9	8	61
Days with Precipitation†	3	2	1	2	1	6	2	0	2	19
Percent of Days with Precipitation†	60	40	50	50	25	50	17	0	25	35 (Ave.)
4. Little Chance										
Total Days	0	0	0	0	0	2	6	5	0	13
Days with Precipitation†	-	-	-	-	-	0	0	0	-	0
Percent of Days with Precipitation†	-	-	-	-	-	0	0	0	-	0 (Ave.)
5. Very Likely and Likely Combined										
Total Days	16	23	16	14	24	11	11	9	8	132
Days with Precipitation†	16	21	15	13	23	11	7	5	8	119
Percent of Days with Precipitation†	100	91	94	93	96	100	64	56	100	88 (Ave.)
6. Not Likely and Little Chance Combined										
Total Days	5	5	2	4	4	14	18	14	8	74
Days with Precipitation†	3	2	1	2	1	6	2	0	2	19
Percent of Days with Precipitation†	60	40	50	50	25	43	11	0	25	34 (Ave.)

† Average Precipitation Amount for the Representative Stations $\geq$ 0.01 Inch (trace not counted)

Table 5-9. Precipitation Probability Compared with Precipitation Amount

Case Number	2	5	1	3	4	3	4	5	1	
Month	April 1963	July 1964	Dec 1964	March 1965	July 1964	March 1964	May 1964	Nov 1964	Dec 1962	
Percent Normal Precipitation	236	211	200	195	179	90	85	76	63	Average All Cases
1. Very Likely										
Number of Days	1	10	4	6	11	1	3	0	2	-----
Total Precipitation on These Days (inches)	0.03	8.75	2.48	1.12	6.44	0.08	2.59	----	1.00	-----
Percent of Total Monthly Precipitation	01	69	48	45	65	06	93	----	51	47
Average Precipitation Per Day	0.03	0.88	0.62	0.19	0.59	0.08	0.86	----	0.50	0.47
2. Likely										
Number of Days	15	13	12	8	13	10	8	9	6	-----
Total Precipitation on These Days (inches)	2.33	3.80	2.67	1.36	3.45	1.04	0.17	1.67	0.94	-----
Percent of Total Monthly Precipitation	92	30	51	54	34	83	06	100	48	55
Average Precipitation Per Day	0.16	0.29	0.22	0.17	0.27	0.10	0.02	0.19	0.16	0.18
3. Not Likely										
Number of Days	5	5	2	4	4	12	12	9	8	-----
Total Precipitation on These Days (inches)	0.17	0.09	0.04	0.03	0.04	0.14	0.02	0	0.02	-----
Percent of Total Monthly Precipitation	07	01	01	01	01	11	01	0	01	03
Average Precipitation Per Day	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0	0.00	0.01
4. Little Chance										
Number of Days	0	0	0	0	0	2	6	5	0	-----
Total Precipitation on These Days (inches)	----	----	----	----	----	0	0	0	----	-----
Percent of Total Monthly Precipitation	----	----	----	----	----	0	0	0	----	0
Average Precipitation Per Day	----	----	----	----	----	0	0	0	----	0
Very Likely or Likely (Combined)										
Number of Days	16	23	16	14	24	11	11	9	8	-----
Total Precipitation on These Days (inches)	2.36	12.55	5.15	2.48	9.89	1.12	2.76	1.67	1.94	-----
Percent of Total Monthly Precipitation	93	99	99	99	100	89	97	100	99	97
Average Precipitation Per Day	0.15	0.55	0.32	0.18	0.41	0.10	0.25	0.19	0.24	0.27
Not Likely or Little Chance (Combined)										
Number of Days	5	5	2	4	4	14	18	14	8	-----
Total Precipitation on These Days (inches)	0.17	0.09	0.04	0.03	0.04	0.14	0.02	0.00	0.02	-----
Percent of Total Monthly Precipitation	07	01	01	01	00	11	01	00	01	03
Average Precipitation Per Day	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.01

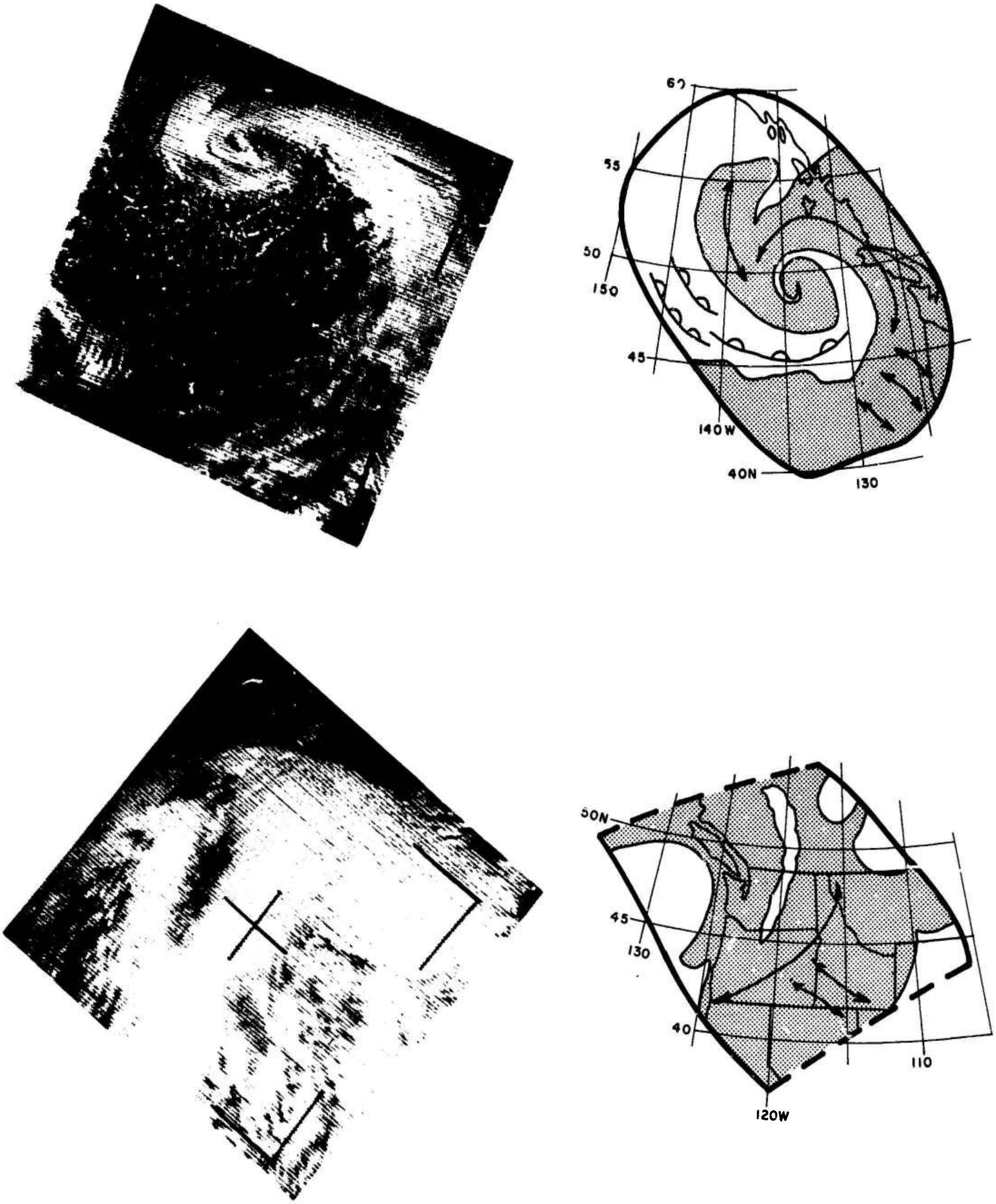

Fig. 5-1 Examples of "Very Likely" Precipitation Probability. Well-Developed Occluded System Seen on Two Consecutive Days. Completely Covered Region, Very Bright Cloud Cover.

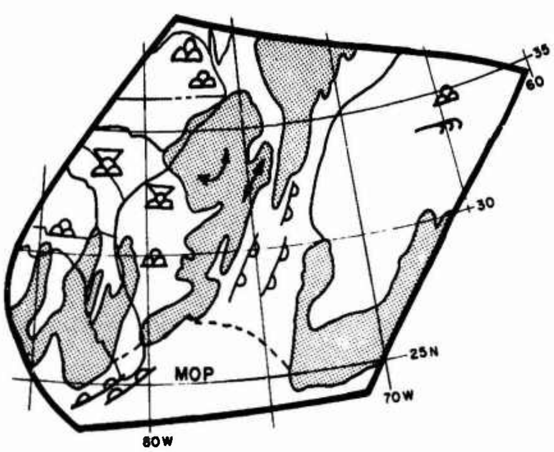

Fig. 5-2 Example of 'Very Likely'' Precipitation Probability. Large Cumulonimbus Blobs.

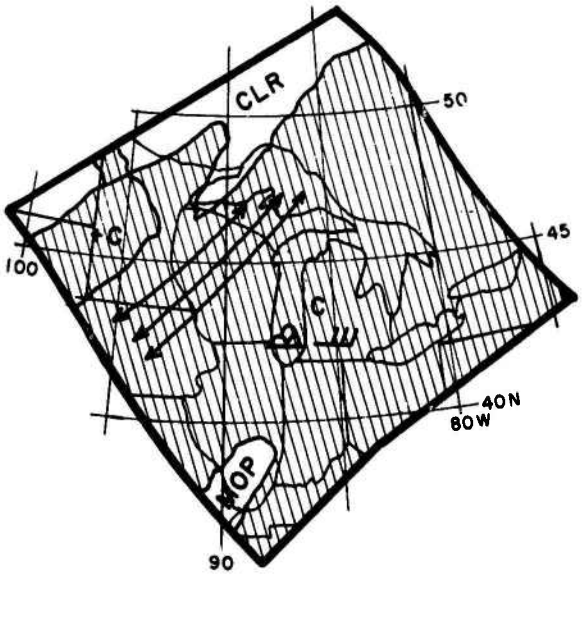

Fig. 5-3 Example of "Likely" Precipitation Probability. Thin Overcast with Open Areas to North. Part of Clouds Probably Cirrus.

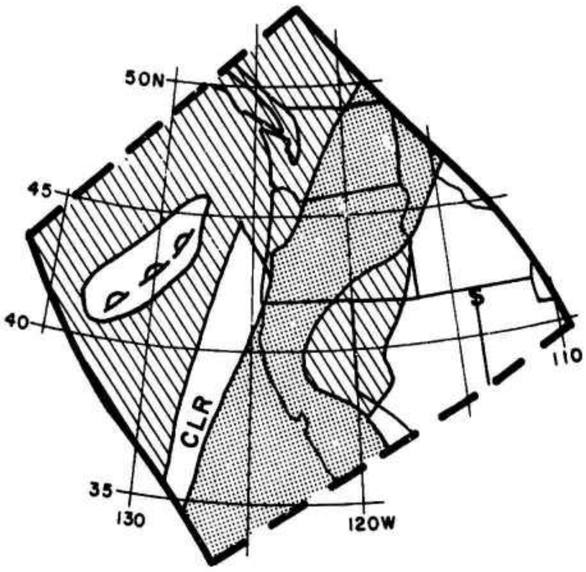

Fig. 5-4 Example of "Likely" Precipitation Probability. Frontal Band; Covered, but with Some Breaks.

Fog or Stratus in Imperial Valley, California

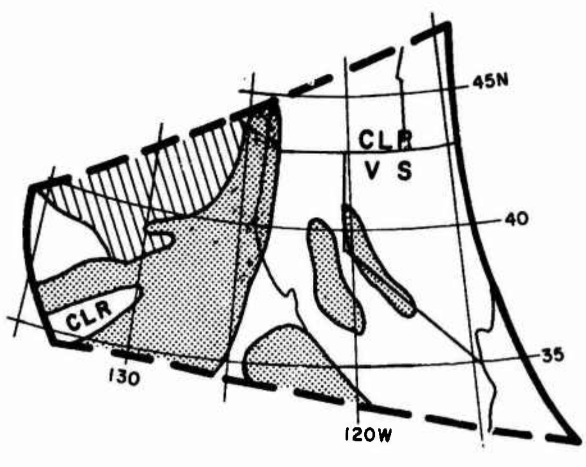

Fig. 5-5 Example of "Not Likely" Precipitation Probability. Mostly Open Except Well to North; Cloud Cover Mostly Stratus and Fog.

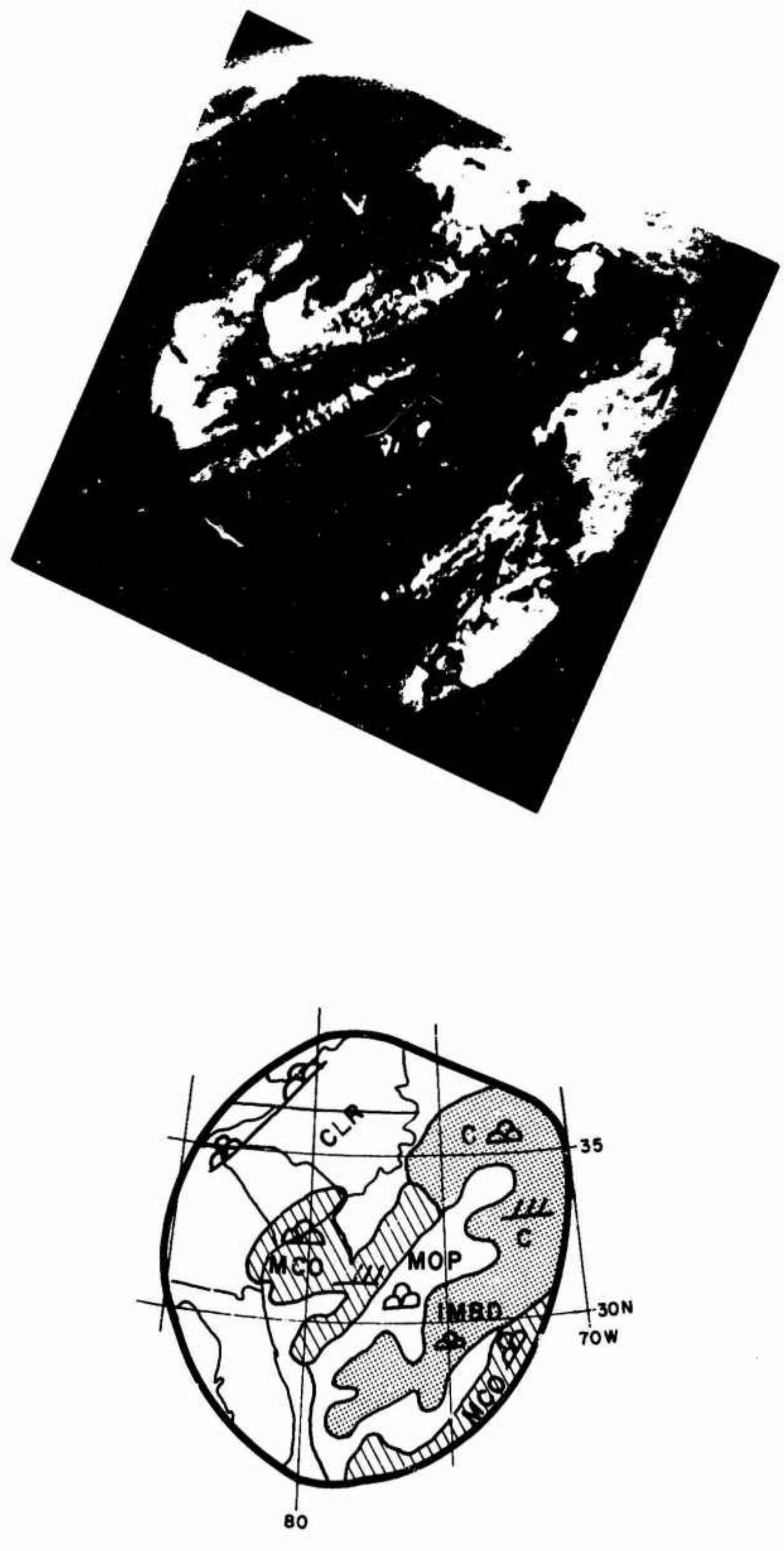

Fig. 5-6 Example of "Not Likely" Precipitation Probability. Mostly Open Except Well to North; Cloud Cover Mostly Stratus and Fog.

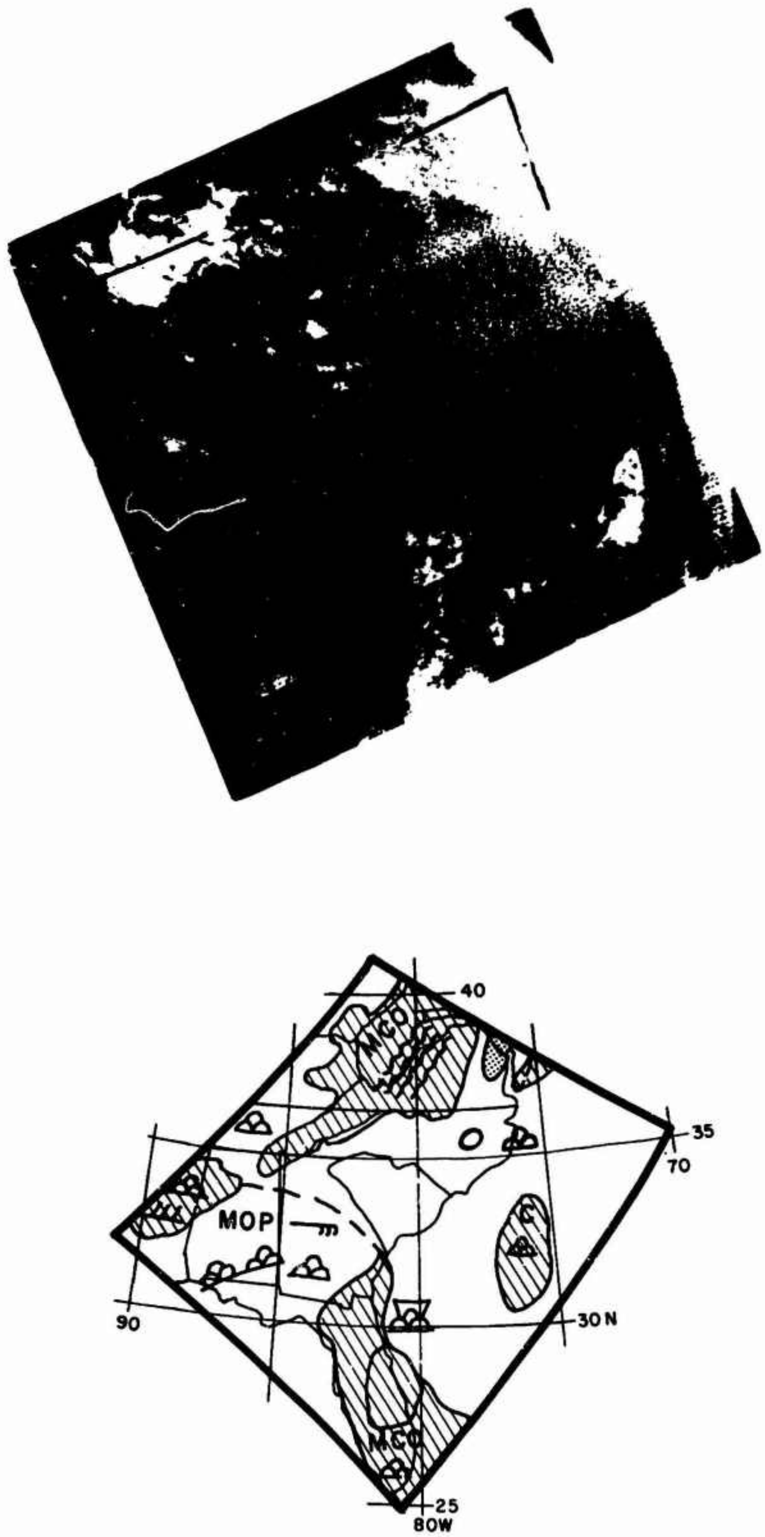

Fig. 5-7 Example of "Little Chance" Precipitation Probability. No Cloud Cover over Region.

in this Table are far more significant than those in Table 5-8. It can be noted that even if precipitation did occur on a day which was assigned a probability of not likely or little chance, the amount of precipitation in nearly all cases was insignificant. In seven of the nine months, either 99% or 100% of the total precipitation occurred on the days with very likely or likely probabilities. In all but two months, the days with the very likely probabilities were those with the greatest averaged amount of precipitation per day.

5.2.4.3.3 Comparison With Precipitation Anomalies

In Table 5-10, the percentages of the number of days with satellite observations that were assigned each probability are compared with the monthly precipitation anomalies. It is seen that the months with positive precipitation anomalies have much higher percentages of days with probabilities of very likely or likely. Furthermore, the ranges of values in this Table are small, increasing the statistical validity of the data. The results shown in this Table suggest that if a month has precipitation probabilities of very likely or likely on 75% or more of the days, the month is likely to have above normal precipitation. Similarly, if a month has precipitation probabilities of not likely or little chance on more than 50% of the days, the month is likely to have below normal precipitation.

In Table 5-11, the percentage of days assigned very likely and likely precipitation probabilities are compared with the normal monthly percentage of days with precipitation (as taken from climatological data). This comparison, therefore, takes some account of the differences in climatic regions, whereas the previous comparisons do not.

For all the months examined, the percentage of days with probabilities of very likely or likely is larger than the normal percentage of days with precipitation. This indicates an over estimation of the probability of precipitation, especially on the low precipitation months and may result from satellite observations being more frequently programmed over major weather systems.* A definite correlation between

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* This over estimation tendency can also be seen in Table 5-8, where six months had more days assigned to very likely or likely than days on which precipitation was actually observed. This ties in with the results of Nagle and Blackmer (Reference 22) who found larger cloud areas appearing as if they might contain precipitation than those actually precipitating at any given time.

Table 5-10. Precipitation Probability Compared With Monthly Precipitation Anomaly

CASE NUMBER	2	5	1	3	4	3	4	5	1
Month	April 1963	July 1964	Dec 1964	March 1965	July 1964	March 1964	May 1964	Nov 1964	Dec 1962
Percent of Normal Precipitation	236	211	200	195	179	90	85	76	63
Total Satellite Observations - Days	21	28	18	18	28	25	29	23	16
Percentage of Days Very Likely	5	36	22	33	39	4	10	0	13
Percentage of Days Likely	71	47	67	45	46	40	28	39	37
Percentage of Days Not Likely	24	17	11	22	15	48	41	39	50
Percentage of Days Little Chance	0	0	0	0	0	8	21	22	0
Percentage of Days Very Likely or Likely (Combined)	76	83	89	78	85	44	38	39	50
Percentage of Days Not Likely or Litte Chance (Combined)	24	17	11	22	15	56	62	61	50

	All Months with Positive Anomalies	Range of Values	All Months with Negative Anomalies	Range of Values
Average Percentage of Days Very Likely or Likely (Combined)	82%	(76-89)	43%	(38-50)
Average Percentage of Days Not Likely or Little Chance (Combined)	18%	(11-24)	57%	(50-62)

Table 5-11. Precipitation Probability Compared with Normal Monthly Precipitation Days

CASE NUMBERS	2	5	1	3	4	3	4	5	1
Month	April 1963	July 1964	Dec 1964	March 1965	July 1964	March 1964	May 1964	Nov 1964	Dec 1962
Total Satellite Observations (Days)	21	28	18	18	28	25	29	23	16
Percentage of Days with Probabilities Very Likely or Likely	76	83	89	78	85	44	38	39	50
Normal Percentage of Days with Precipitation $\geq$ 0.01 inch	33	45	45	32	42	32	29	23	45
Difference Between Satellite Probable Days and Normal Days with Precipitation (Percent)	43	38	44	46	43	12	9	16	5
Percent of Normal Precipitation for Month	236	211	200	195	179	90	85	76	63

Average Difference Between Satellite Observed Probable Days with Precipitation, and Normal Days with Precipitation

All Months with Precipitation Above Normal = 43% (Range 38-46%)

All Months with Precipitation Below Normal = 11% (Range 5-16%)

the precipitation anomaly and the magnitude of the differences between the satellite observed probable precipitation days and the normal precipitation days does exist, however, and the ranges of values are small increasing the statistical validity. The sample studied suggested: a) if the ratio of the percentage of satellite observed probable precipitation days to the percentage of normal precipitation days is $\geq$ 1.4, the month is likely to have above normal precipitation; b) if this ratio is $\leq$ 1.2, the month is likely to have below normal precipitation.

5.2.4.4 Discussion of Results of Satellite Picture Study

The results of the satellite picture study, described in Section 5.3, are most encouraging. It appears that satellite data can provide a good indication of the probability of occurrence of precipitation over a region and, to a degree, of the amount of precipitation (especially as anomalies over periods of the order of a month). There are, of course, shortcomings and problems that have come to light in this study, some of which are due to the limited data sample and some of which are inherent in the sources of data that were available for this study.

It is obvious that the precipitation probabilities assigned most frequently are those of likely and not likely. Very likely and little chance are seldom assigned during some months. Of the four probabilities, one that can be assigned with the highest degree of confidence is little chance. This is, of course, due to the basic mechanics of precipitation, i.e., clouds must exist for precipitation to occur, but the existence of clouds does not mean that precipitation will occur. This is further substantiated in a study of a number of the days on which the rainfall amount did not correlate with the assigned probability. This study revealed that the probability assigned was too high on twice as many days as it was too low. In other words, on many cloudy days, it does not precipitate! (This, of course, was clearly evident in Tables 5-8 and 5-11.)

Thus, it would appear that the principal reason for over estimating the probability is that precipitation did not occur from the cloud cover in question or that only a small part of the cloud cover precipitated, with the precipitation not being recorded at any of the data stations. In a number of the "underestimated" cases that were re-examined, either there was no apparent organization in the cloud cover, or the cloud texture was very smooth.

In the cases where the precipitation probability was underestimated, the variability of shower-type rainfall appears to be the principal reason. In a few cases, a shower at just one station was heavy enough to lead to a large average amount of precipitation for the entire region. In approximately one-quarter of all the cases which were assigned incorrect probabilities, the satellite was viewing only a part of the region or was viewing the region at a high nadir angle. It is anticipated that this problem will be reduced to a minimum with the improved coverage to be provided by the TOS System (ESSA Satellites).

Difficulties arise in estimating precipitation amount because of the uncertainty in determining the movements of systems, especially when viewed only once per day. Also, seasonal differences may be an important factor; certain regions may be cloud covered for several days during winter with very little precipitation occurring, while other regions may have precipitation on nearly every day that convective activity occurs in the summer. The total amount of precipitation is also strongly influenced by season, due largely to the varying amounts of moisture available.

5.2.4.5 Discussion of Selected Cases to Illustrate Specific Points of Interest and Problems that May be Encountered

5.2.4.5.1 Case 4, May 1964

The satellite data can also provide an indication of the precipitation regime during individual portions of a month, and such a day-by-day study may show the monthly precipitation totals to be misleading. An example of this is Case 4 (North Carolina, South Carolina, Eastern Georgia), May 1964, where a monthly percent of normal precipitation of 85% does not tell the whole story. Although the negative precipitation anomaly was not very large, nearly all of this precipitation (2.35" out of a total of 2.78") fell during the first three days of the month. Thereafter, the month was extremely dry with some stations reporting near record dry spells.

The precipitation pattern over the region during this month is clearly depicted by the satellite data. The storm system that brought the heavy rain moved across the region on the 2nd and 3rd (Fig. 5-8). Both of these days were given probabilities of very likely. From the 4th through the 27th, there were no very likely days, only four likely days, twelve not likely days, and six little chance days. During this entire period, less than a quarter inch of rain was recorded. On the 28th, 30th, and 31st probabilities of likely were assigned and small amounts of precipitation (an

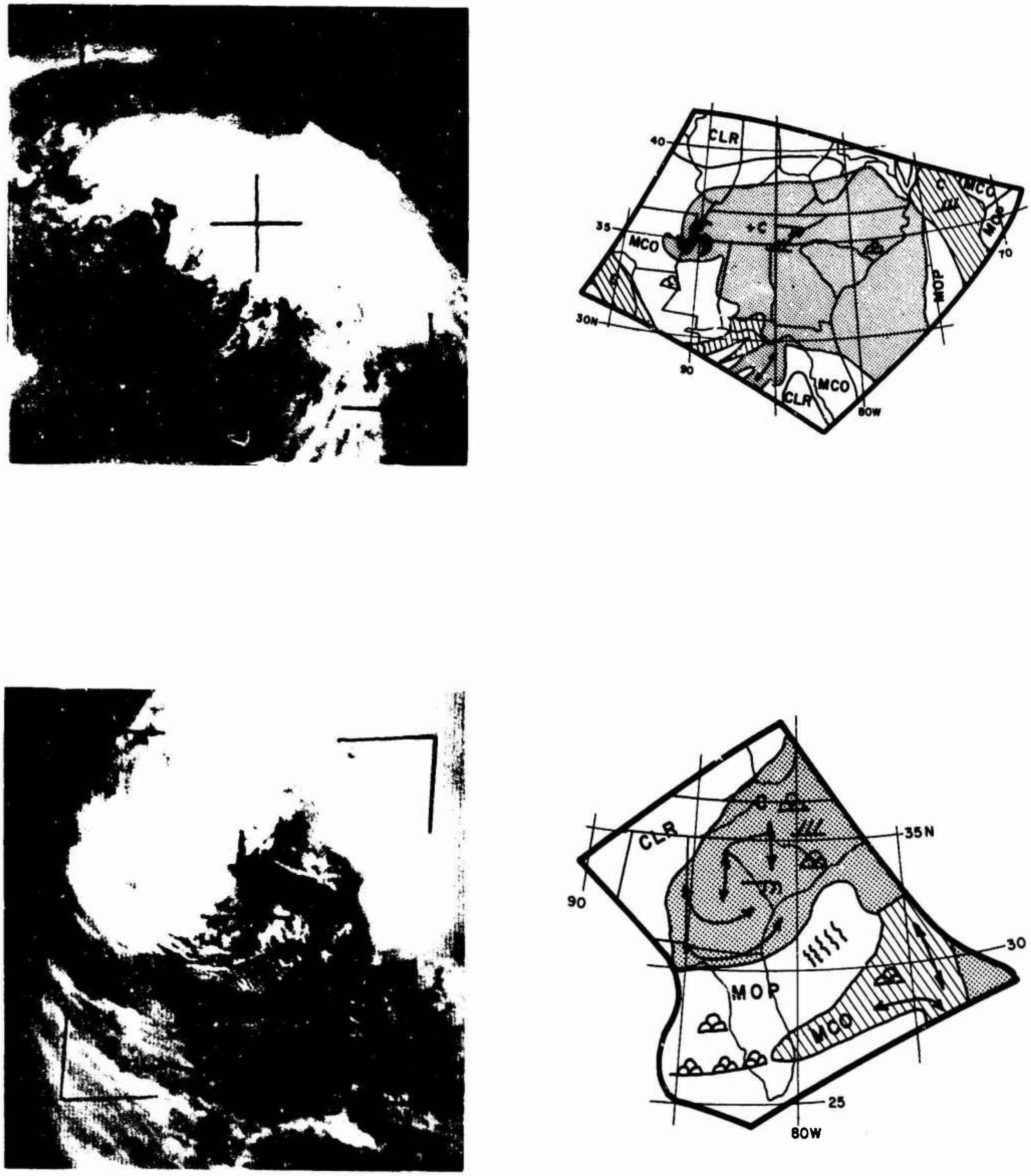

Fig. 5-8 Well-Developed System over Region on Two Successive Days. Completely Covered, Very Bright. "Very Likely" Precipitation Probability.

average of 0.05" per day) did occur on each day. On the 29th, a very likely probability was assigned, as a well developed frontal band appeared over the region. More than a quarter inch of rain fell on this day, the third highest amount during any single day of the month.

5.2.4.5.2 Snake River Plains Case

While examining pictures for Case 1 (Pacific Northwest, December 1962), it was observed that a bright area virtually unchanged in shape, from the 8th through the 13th of the month. A check of the geographic location and configuration of the bright area revealed that it was the Snake River Plains area of Southern Idaho. The area is shown on two separate days in Figure 5-9.

Satellite pictures of the same region in the other month of Case 1, December 1964, showed a similarly shaped area on three different days except that in 1964 the area was dark. The location and shape of the area revealed that it was also the Snake River Plains area. Figure 5-10 shows the area on 4 and 6 December 1964.

Here, then, are pictures of the same terrestrial feature, viewed at the same time of year, and yet appearing exactly opposite in tone. In one year, the feature is bright against a dark background and in the other year, the feature is dark against a bright background. An examination of other satellite, surface observation, and climatological summaries provided the answer to this puzzle.

The Plateau region was under the influence of a large upper level ridge during nearly the entire first half of December 1962. During the period from the 8th through the 13th, skies were generally cloud free and fog was reported every day from many stations, including Pocatello and Boise in the Snake River Plains area. Conventional data show that very little precipitation occurred during the late fall of 1962 and, in southern Idaho, December 1962 was the driest December since 1888. Because of this, there was little snow pack in the mountains.

In December 1964, on the other hand, precipitation was very heavy throughout the region and, in some parts, it was the wettest (snowiest) December on record. Although considerable snow had fallen in the early days of the month, surface charts indicate generally clear skies on the days of the pictures shown in Figure 5-10.

It is concluded, therefore, that in December 1962 the satellite was viewing a fog covered river valley within a mountain area almost entirely devoid of snow cover. In December 1964, it was viewing the same river valley, clear of fog, but surrounded by mountains that are entirely snow covered. The sharp edges to the bright area in

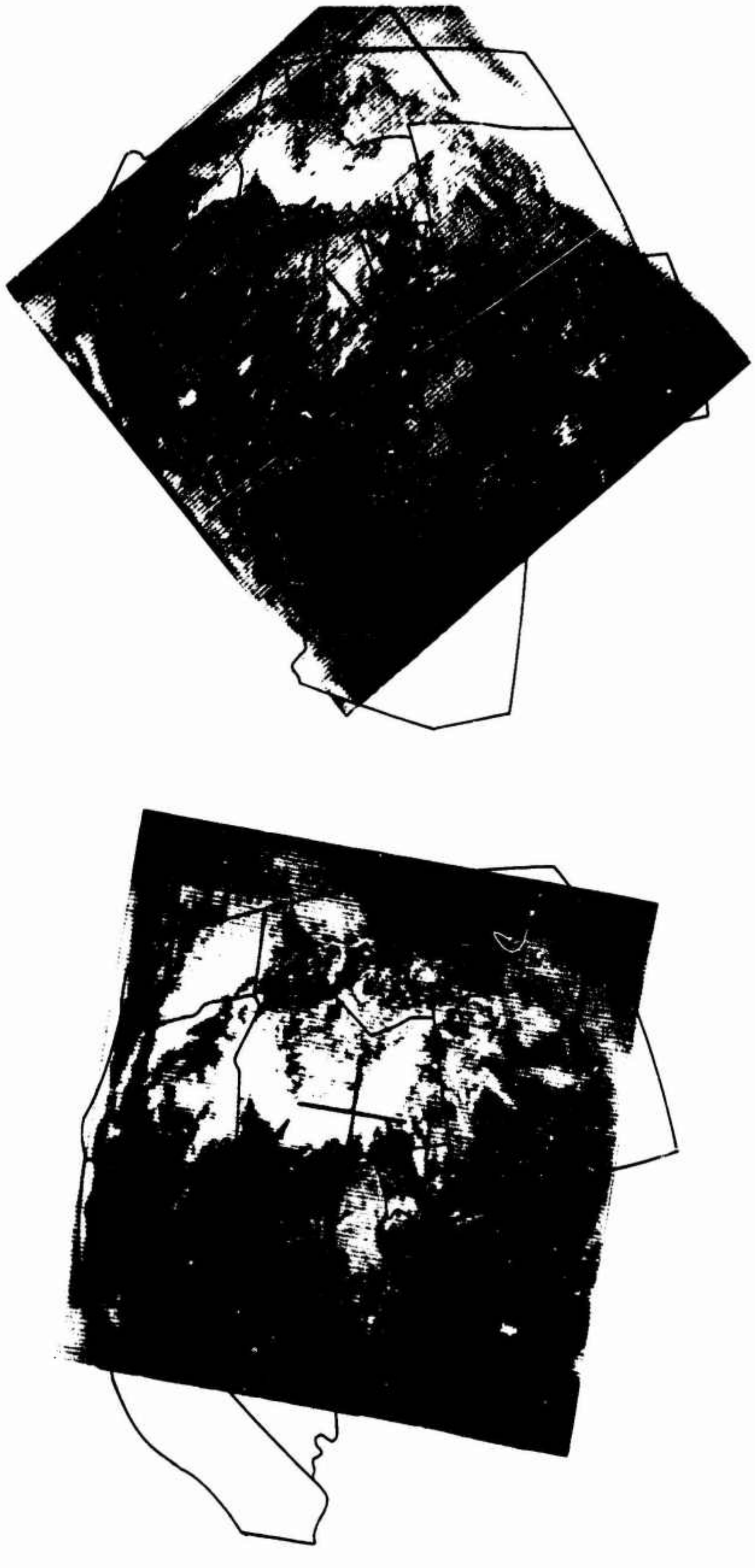

Fig. 5-9 Snake River Plains Region on Two Successive Days. Low Areas Fog Covered; Little Snow.

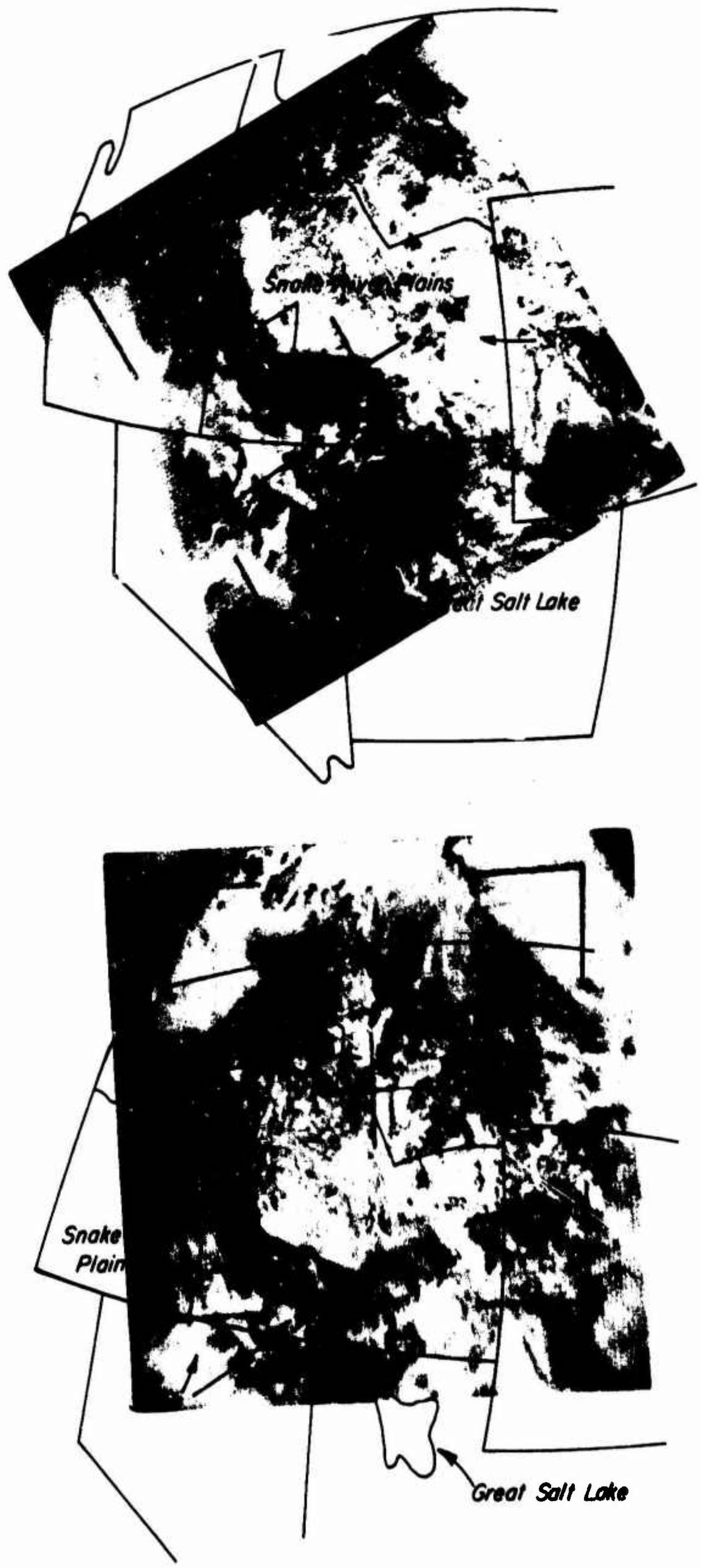

Fig. 5-10 Snake River Plains Region with Snow Cover in Mountains.

Figure 5-9 indicate that the fog ends abruptly at the higher terrain; the dendritic pattern, characteristic of snow cover in mountain areas, is clearly seen in parts of the pictures of Figure 5-10.

This interesting case demonstrates that only a few satellite pictures could give an indication of the recent precipitation regime of a particular region. The ability of the satellite to observe the snow cover or lack of snow cover in a mountainous region certainly could be of value to Army interests. Moreover, the series of observations in December 1962 demonstrate the satellite's ability to determine fog covered valleys; an ability directly applicable to Army requirements for reconnaissance and bombing.

This case also demonstrates the care that must be taken when interpreting features in the satellite data and the need for correlating all present and past data from all available sources.

5.2.5 Conclusions

The studies undertaken under Task D, Phase 2, indicate that meteorological satellite data can be of considerable value to the Army by providing vital information about longer term weather effects on enemy operations. Much more reliable information can be extracted from the satellite pictures directly (the form in which the data would be presented in an APT system) rather than from the nephanalyses. However, even the nephanalyses provide some useful information; this could be important to the Army, especially if the analyses are to be made at an overseas central which lacks access to APT or other meteorological pictures but does receive the facsimile nephanalyses.

Based on the limited sample of data that has so far been examined, it would appear that for areas with climatic regimes similar to the United States, months with sufficiently anomalous precipitation (i.e., greater than 150% of normal or less than 75% normal for the area and season of interest) can be identified by skilled interpreters with a reliability of perhaps 80% using only the nephanalyses. When the pictures themselves are examined, the reliability of identification of anomalous precipitation situations should increase to perhaps 95%.

The study has shown that the satellite can also provide reliable estimates of the daily probability of the occurrence of precipitation over limited regions, as well as the precipitation probabilities integrated over a few days to a month. It appears that satellite observations, although in themselves nearly instantaneous, can be

correlated most reliably with precipitation occurrence integrated over a time period of as much as one day. This is in agreement with previous findings which used radar observation as an aid interpreting satellite cloud observations (Reference 22).

One of the major problems encountered in this preliminary use of satellite data for the determination of long term weather effects was the incompleteness of the presently available data. It is anticipated that, with the implementation of the TOS system scheduled in the near future, this problem will be greatly reduced and perhaps even be essentially eliminated.

5.2.6 Recommendations

The results of the study are extremely encouraging, but it is realized that the conclusions have been drawn from only a limited data sample. Further work is needed to provide greater statistical validity and to develop more refined techniques and more objective procedures. The actual satellite pictures should be studied for all of the cases for which nephanalyses were studied and other cases, both in the United States and other regions of the world, should be examined. A far wider variety of climatic regimes should be included in the sample. The additional cases should include several with periods of near normal conditions as well as the periods with anomalous precipitation emphasized in this study. Temperature regimes should be studied, both alone and as associated with precipitation probabilities. These further studies should provide more definite methods, for use by the Army, for the determination of the several vital factors affecting enemy operations which result from the long term effects of weather.

6. PROCEDURES AND TECHNIQUES FOR THE OPTIMUM USE OF SATELLITE DATA IN THE FIELD - TASK E

The use of meteorological satellites as an observing tool is relatively new to weather analysis and forecasting. Therefore, the technical guidelines for the contract requested that a considerable effort be devoted to the development of procedures and techniques for the optimum employment and application of these data. During the course of the contract, considerable effort was expended on this task, resulting in the preparation of three major sections on field interpretation techniques and a large section on acquisition and location of APT data for the Operation Guide (Reference 36 and 37).

These sections of the Operational Guide are explicit and need not be repeated here. However, a brief summary of each of the four sections follows.

6.1 Acquisition and Geographic Location of APT and DRIR Data

The APT (Automatic Picture Transmission) system allows direct readout of the satellite data to field units having the appropriate small antenna, receiver, and recorder. The transmission is automatic and immediate. The detailed section of the Operational Guide provides Army personnel with the information and procedures required for:

1. Determining the orbits, subpoint tracks, and look-angle elevations of APT- and/or DRIR-equipped satellites passing within range of their location.

2. Tracking the satellite with the APT antenna and acquiring the data (APT pictures or DRIR data).

3. Geographically locating the data.

Information on Orbital Considerations is also provided in Volume II of the Guide (Reference 37)and is vital to the understanding and application of the information and procedures discussed in the acquisition section.

6.2 Interpretation of Meteorological Satellite Data by Army Personnel Having No Significant Weather Training

Many types of interpretation of the satellite pictorial data are possible, ranging from simply the basic interpretation of the content of the picture in terms of cloud cover or the simplest aspects of the local weather situation, up to the broader interpretation of the picture in terms of the weather situation prevailing in the field Army and adjacent areas. Material on these matters is provided in Volume I of the Operational Guide (Reference 37). That section of the Guide also deals with necessary terms and definitions required for such interpretation, and with the types of data available.

6.3 Interpretation of Meteorological Satellite Data by Army Personnel with Limited Meteorological Training and Experience

Volume I of the Operational Guide also includes further guidance for such Army personnel as

1. Pilots
2. Artillery Meteorological Officers, Warrant Officers, and Senior Non-Commissioned Officers
3. Intelligence or other Officers whose responsibilities include a direct concern for weather

For that discussion, it was assumed that field personnel were familiar with the information comparable to that provided in TM 1-300, Meteorology for Army Aviation. Thus, in addition to the techniques presented in the section for non-meteorologically trained personnel, other subjects and additional techniques could be discussed.

6.4 Interpretation and Application Procedures for Professional Meteorologists

The most extensive use of the meteorological satellite data can be made by professional meteorologists who can effectively integrate the data with available conventional synoptic data, available climatological data, and their previous experience to provide extremely useful analyses and prediction under field conditions. A comprehensive summary of these techniques has been prepared by ARACON personnel under a previous contract (Reference 35) which has been made available to the meteorological community (both military and civilian).

The resources of the present contract did not permit the redrafting of all of this material into the Operational Guide. Rather, six major sections from this manual have been provided to supplement Reference 35 as required by the results of subsequent research and technique development (especially the results described in Sections 3 through 5 of this report). These six new sections are included in the Guide and discuss techniques for:

1. Cloud interpretation at improved resolution
2. Improved extratropical vortex interpretation
3. Interpretation of mesoscale features
4. Single station techniques for the integrated use of satellite data and (1) radar data and local surface observation, (2) local surface and radiosonde data, and (3) local radar, radiosonde, and surface conventional data. Included also are interpretation techniques for silent data areas and for friendly areas where only

limited conventional data is available. (Examples of such techniques are also detailed in Section 3 of this Final Report.)

5. Field prediction procedures
6. Interpretation of infrared data
   a. Meteorological interpretation of Nimbus High Resolution Infrared (HRIR) Data

It is believed the above cited material in the Operational Guide provides a complete summary of the present state-of-the-art of field procedures and techniques for the use of meteorological satellite data at three levels of training and experience: (1) no significant weather training; (2) limited, non-professional training; and (3) when used to supplement Reference 35, professional meteorologists.

7. ANALYSIS AND PREDICTION PROCEDURES -- TASK F

During the course of the research performed under this contract, several analysis and prediction procedures gleaned either directly or indirectly, from the results of other tasks. These have been described in some detail in Section 5 of the Operational Guide (prepared under this contract). These procedures will not be detailed here since they are included (with one exception) in other sections of this report. Thus, only a brief summary follows. The one exception (snow cover) is described in more detail in Section 7.2.

7.1 Prediction Procedures for Mesoscale Features

During the course of the recent studies, emphasis was placed on obtaining meteorological data for use by Army Field Personnel which is directly applicable to the short range, relatively small area field prediction problems. These included analyses procedures for using the integrated satellite data and conventional data in the prediction of:

1. Local severe storms (see also Section 4 of this report)
2. Low level winds (see also Section 3.5 of this report)
3. Cloud persistence (see also Section 4 of this report)
4. Precipitation probabilities (see also Section 5 of this report)
5. Mesoscale holes in a cloud mass (see also Section 3.5 of this report)
6. Areas of fog or low stratus (see also Section 3.5 of this report)

7.2 Synoptic Scale Prediction Procedures

Several synoptic scale prediction procedures for synoptic scale features are detailed in Chapter 12 of Reference 35. Some supplemental information and techniques detailed in the Guide are outlined below:

1. Low level winds (see also Section 4.2 of this report)
2. Atmospheric structure (see also Section 4.2 of this report)
3. Snow cover

Under a separate contract (Cwb-11269), ARACON personnel have been investigating the feasibility of assessing snow cover and snow amounts from the satellite pictures. Although the contract is not yet complete, it has been determined that personnel experienced in satellite data interpretation can almost always distinguish snow cover from clouds in the photographs. In addition, bright appearing snow areas can often be analyzed in terms of 1) little to one inch, and 2) a high probability of greater than five or six inches.

The analysis is based principally on the variation of brightness (or shades of grey). Although such an analysis is somewhat subjective, the meteorologist would have some direct evidence upon which to brief commanders on the probable snow cover over enemy territory. Assessments could then be made about probable trafficability problems of the enemy or of the advancing allied troops. An example, showing the correspondence of the bright areas in the TIROS picture to conventionally measured snow amounts is shown in Figure 7-1.

It must be pointed out, however, that under certain conditions, forested areas can be deceiving because they do not show as brightly as surrounding areas with the same amount of snow on the ground (Reference 8). At other times, the forested area, especially when the forest is made up principally of conifers, will indicate snow before it is clearly visible on the surrounding grounds. For example, wet, heavy snow will often stick to coniferous trees and thus show as relatively bright areas in the pictures. Figure 7-2 shows the Appalachian Mountain area during the winter of 1964. The bright areas can be deduced to be snow since such geographical features as Lake Ontario, Lake Champlain, the St. Lawrence River, etc. are visible. The dark area near "A" appears less bright due to the snow being somewhat hidden by the forest.

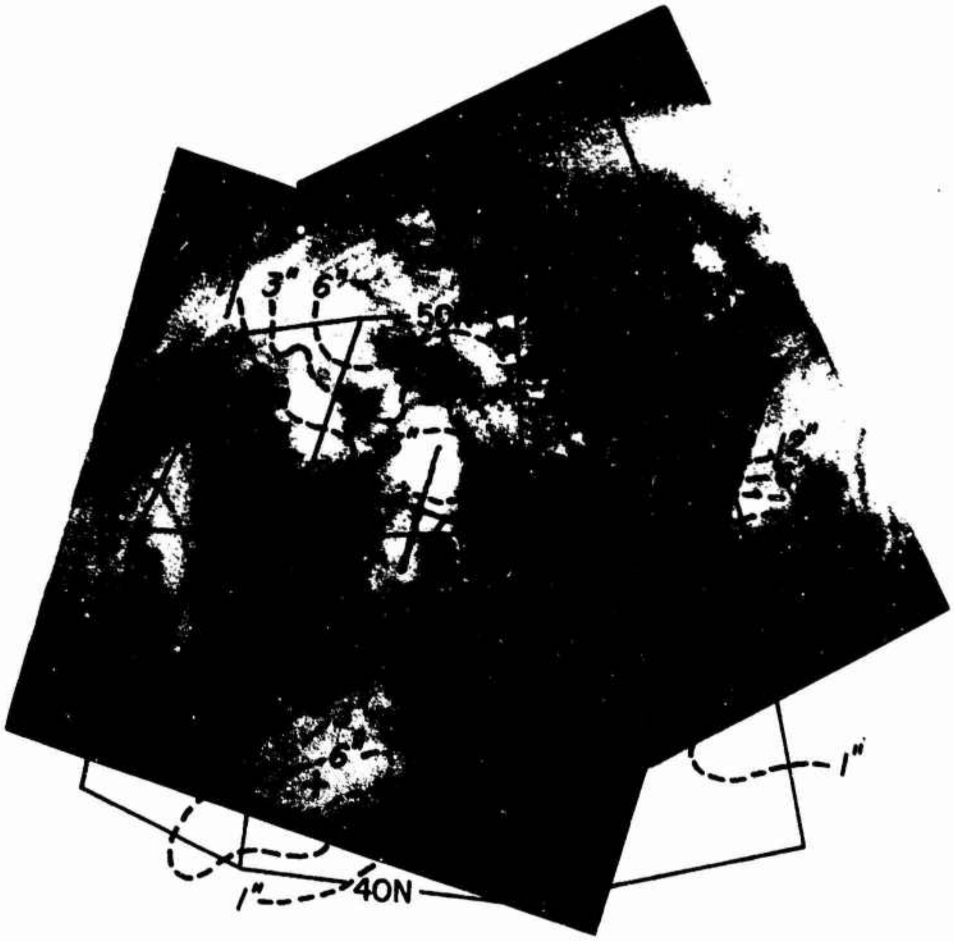

Fig. 7-1 TIROS Pictures and Conventionally Measured Snow Analysis.

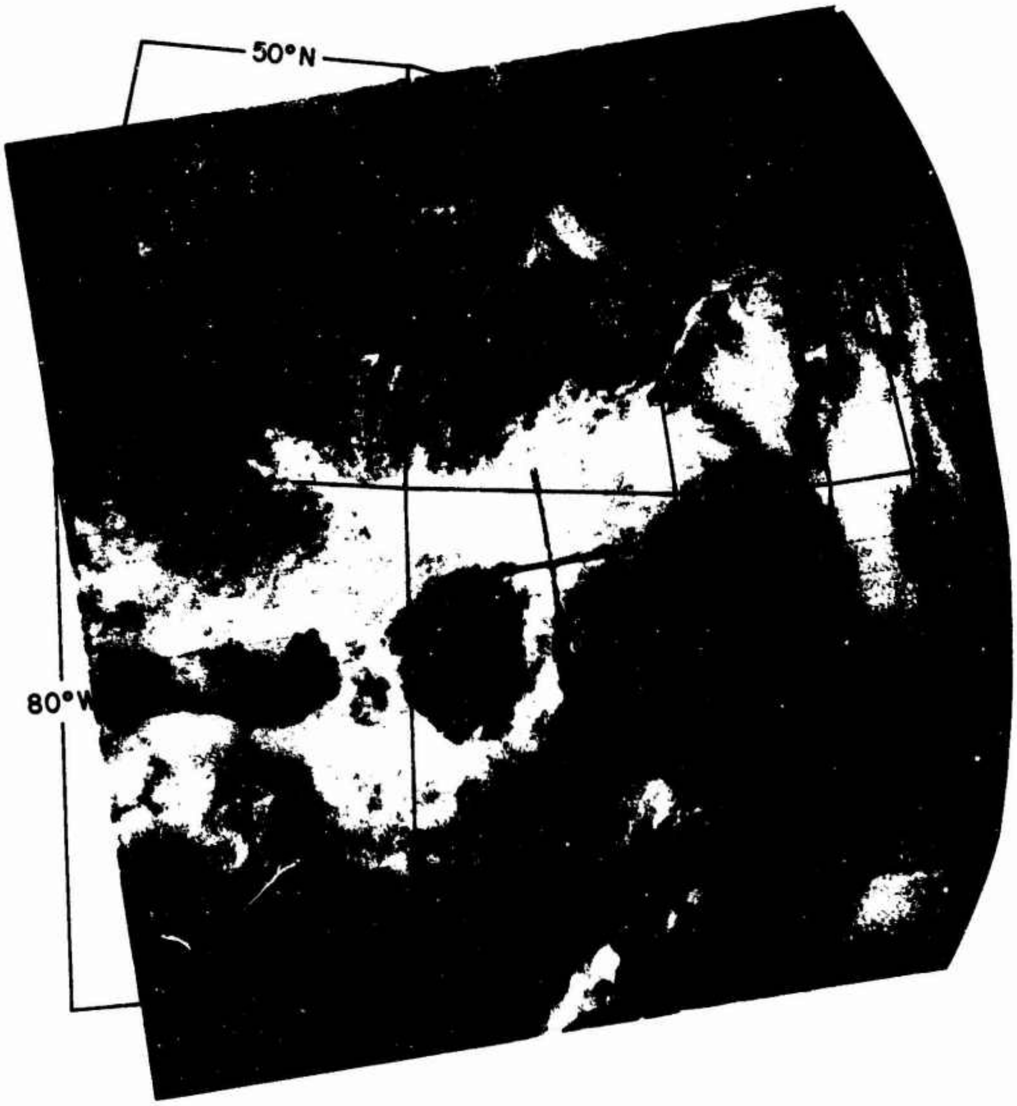

Fig. 7-2 ESSA I Photograph. Snow Cover is Present Over This Essentially Cloud-Free Picture. North of about 41°N Snow Depths Range from One to Six Inches in Lowland Areas and up to Several Feet in the Mountains. The Bright Areas are Mostly Open Land and the Forested Areas Appear Dark Despite the Snow Cover. The Adirondack Mountains (43°N, 74°W) are Especially Dark Due to Coniferous Forest and Form an Easily Recognizable Pattern in Wintertime Satellite Pictures.

These pictures clearly indicate, however, that the meteorologist may be able to provide area commanders with estimates of snow amounts for enemy held territories into which the Army may be advancing.

8. OPERATIONAL GUIDE -- TASK G

The technical guidelines for this contract list as an objective, the preparation of an operational guide (or handbook) that can be used by Army and supporting personnel charged with the responsibility for providing and applying meteorological data and weather information and predicitions. This task has been fulfilled and the Operational Guide (References 36 and 37) has been published, as mentioned above. This Guide provides satellite data interpretation techniques for three levels of Army personnel, i.e., personnel without significant meteorological training, personnel with limited meteorological training, and professional meteorologists.

The following is a very brief abstract of the Table of Contents:

<u>Operational Guide for the Interpretation and Application of Meteorological Satellite Data for Army Uses</u>

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13. ABSTRACT The research discussed in this report was aimed at providing Army field units with techniques for the use of weather satellite data, especially APT (Automatic Picture Transmission) & DRIR (Direct Readout Infrared) data. The results under each of the several tasks are discussed. These include: 1) Mesoscale analysis and interpretation studies, with particular emphasis on severe local storms, squall lines, improved interpretation techniques for higher resolution(Nimbus AVCS)TV data, & cloud persistence studies; 2) An analysis of Army requirements for application of weather satellite data; 3) Case studies, which used data analogs of selected World War II & Korean campaigns.These cases were analyzed to demonstrate the utility of satellite data at the synoptic scale. In addition,a U.S. field maneuver, for which concurrent satellite data existed, was analyzed to demonstrate mesoscale & synoptic scale uses of satellite data; 4) Investigations of methods for determining weather affecting Army operations, with particular emphasis on determining (a) sub-normal & abnormal precipitation amounts over periods of ten days and a month, & (b) snow cover anomalies; 5) Development of procedures for field use of met datellite data, with emphasis on mesoscale analyses & short-term prediction techniques; 6) The preparation of an Operational Guide.

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